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Original Communications

PERMANENT TOTAL BY-PASS OF THE PULMONIC VALVE

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IN previous publications a technique was presented for circumventing the pulmonic valve[1-5] The relevance of this research to the problems of congenital cyanosis was mentioned in these reports Pulmonic stenosis and atresia—about 70 per cent of cases of cyanotic congenital heart disease—will present many pathological variants refractory to valvulotomy or the direct surgical approach. This is also true of the remaining 30 per cent comprising tricuspid atresia, truncus arteriosus, complete transposition, and other malformations The technique described herein provides egress from the blocked cardiac chamber and is being applied with equal success to the right and left ventricles at the present time[6]

As previously reported, a homologous vena cava was sutured end-to-side to the junction of left and main pulmonary arteries and affixed to a plastic tube which was inserted into the pulmonary conus of the right ventricle The main pulmonary artery just distal to the valve was then totally occluded by ligature, thus diverting the entire cardiac output through this new pulmonary artery (Fig 1) One year follow-up studies on this series of animals showed that the operative procedure was tolerated well, both immediately and remotely, and that the shunt closely simulated a valveless pulmonary artery[5] Evidence was presented that the absence of a pulmonic valve over this one-year period seemed to have no significant untoward effect on cardiac function This publication presents data on those animals studied three and one-half years postoperatively

METHODS

Four of the 8 animals with main pulmonary artery ligation were sacrificed just over a year postoperatively (Group A), and the other 4, about three and

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one-half years after operation (Group B) Both groups were run on the treadmill two to three months postoperatively, and those in Group B were given the same exercise again just before sacrifice A few days after the first practice run on the treadmill, the duration of the second run was recorded at 4 5 miles per hour on a 10 degree incline Other observations included pulse and respiratory rates, and duration of the recovery period

Just before sacrifice, intravascular pressures were recorded under anesthesia with the open chest and intermittent insufflation of the lungs Hamilton and Sanborn manometers were used in Groups A and B, respectively Polyviso recording equipment was used in both groups

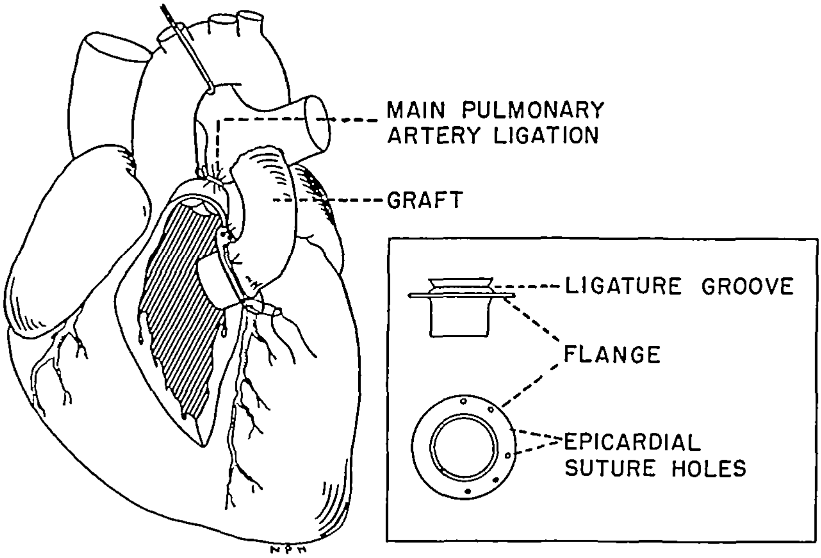

Fig 1 —Diagram of extracardiac shunt with main pulmonary artery ligation

RESULTS

Table I summarizes the data on a series of 12 animals The two operative deaths were due to improper cardiotomy The one postoperative death was due to rupture of a vein graft which was small and unevenly applied to the tube The remaining 9 animals were well postoperatively One of the 9 had a tube too short to reach the ventricle, and the main pulmonary artery was not ligated Table II shows the treadmill results of the 8 animals with main pulmonary artery ligation

Table III summarizes the physiological and anatomical data Since cardiac outputs are not recorded, the pressure gradients across the shunts do not accurately quantitate the degree of stenosis It is interesting, however, that the average gradient (excluding the dog with the aneurysm) was 4 mm Hg, a low value even at basal cardiac outputs[7] In no dog was there stenosis of the suture anastomosis In one animal the stenosis was due to constriction of

TABLE I RESULTS OF OPERATIVE SERIES

DOG	TUBE	POST OPERATIVE DURATION IN MONTHS	CAUSE OF DEATH	CONDITION OF DOG	CONDITION OF SHUNT	REMARKS
19	Teflon	42.0	Sacrificed	Excellent	Patent	—
20	Teflon	14.3	Sacrificed	Excellent	Patent	Graft slightly small
21	Teflon	14.2	Sacrificed	Excellent	Occluded	Tube too short to reach ventricle
22	Lucite	0.5	Hemorrhage	Excellent before rupture	Patent ruptured	Graft uneven and small
23	—	Operative death	Ventricular fibrillation	—	—	Cardiotomy too large poor resuscitation
24	Lucite	42.7	Sacrificed	Excellent	Patent aneurysm	Nutrition of donor poor, graft contaminated
26	Lucite	30.0	Sacrificed	Excellent	Patent	—
28	—	Operative death	Ventricular fibrillation	—	—	Cardiotomy too small poor resuscitation
29	Lucite	13.4	Sacrificed	Excellent	Patent	Plaque caused stenosis
30	Lucite	13.3	Sacrificed	Excellent (mange)	Patent	—
31	Lucite	13.3	Sacrificed	Excellent	Patent	—
33	Lucite	42.0	Sacrificed	Excellent	Patent	—

the graft formed in preparation In the others, however it was uniformly located at the tube-vessel junction The usual cause of the slight stenoses was the abrupt angulation of the graft at the tube-vessel junction The average diastolic pressures in the right ventricle and pulmonary artery were 2 and 3 mm Hg, respectively The mean right atrial pressures averaged 4 mm Hg or 2 mm higher than the diastolic pressures in the right ventricle The left atrial pressures in Group B averaged 5 mm Hg or about 1 mm Hg higher than the average right atrial pressures in Groups A and B

Angiocardiography at six to eight months postoperatively demonstrated shunt patency in the 8 animals Fig 2 shows the typical anatomy of the new

TABLE II. TREADMILL RUNS AT 4.5 MILES PER HOUR ON TEN DEGREE INCLINE

GROUP	DOG	POSTOPERATIVE DURATION	MINUTES ON TREADMILL
A	20	2.8 months	24
A	29	2.1 months	20
A	30	2.1 months	30
A	31	2.8 months	30
B	19	3.1 months	30
		3.6 years	32
B	24	2.3 months	30
		3.3 years	30
B	26	2.2 months	26
		3.3 years	25
B	33	3.5 years	25

TABLE III SUMMARY OF ANATOMICAL AND PHYSIOLOGICAL STUDIES

GROUP	DOG	PRESSURES IN MM Hg MEAN R.V	 MEAN P A	 GRADIENT	 DIASTOLIC R V	 DIASTOLIC P A	HEART WEIGHT IN GM	BODY WEIGHT IN KG	ESTIMATED HYPERTROPHY RT VENTRICLE	REMARKS
A	20	12	9	3	0	0	176	16	++	Constriction of graft in preparation
A	29	13	9	4	2	3	167	15	+++	Plaque caused stenosis
A	30	15	11	4	0	2	147	15	+	—
A	31	13	12	1	2	?	155	14	++	Dog anoxic during pressure studies
B	19	19	16	3	4	4	135	16	+	Slight angulation and stenosis at stress area
B	24	36	20	16	0	3	191	16	+++	Aneurysm compressed graft at stress area
B	26	20	15	5	5	5	110	16	+	Slight angulation and stenosis at stress area
B	33	18	9	9	0	2	154	16	++	Slight angulation and stenosis at stress area

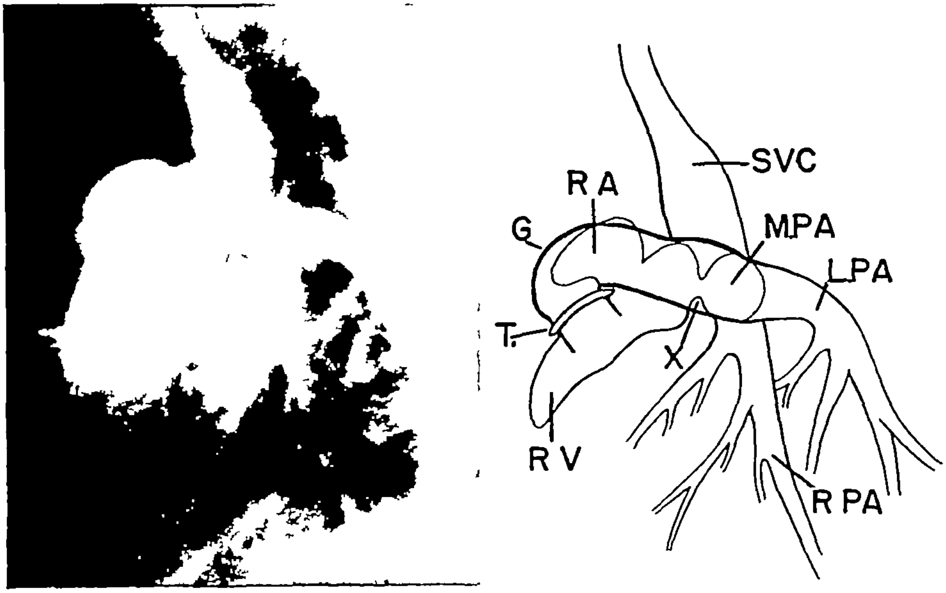

Fig 2—Diodrast angiocardiogram with explanatory diagram In the latter *R V* denotes right ventricle *T* tube *G* graft *R A* right auricle *X* point of ligation *S V C* superior vena cava *M P A* main pulmonary artery *L P A* left pulmonary artery *R P A* right pulmonary artery

channel demonstrated radiographically One animal (No 24) had an aneurysm at the tube vessel junction The wall of the aneurysm was composed of healthy fibrous tissue and was partially lined with a thin clot Despite 3 litters of pups and 3 runs on the treadmill, this aneurysm had not enlarged significantly or ruptured over the three-year period It encroached on the lumen of the shunt, however, and caused the most marked stenosis and myocardial hypertrophy seen in these animals (Table III)

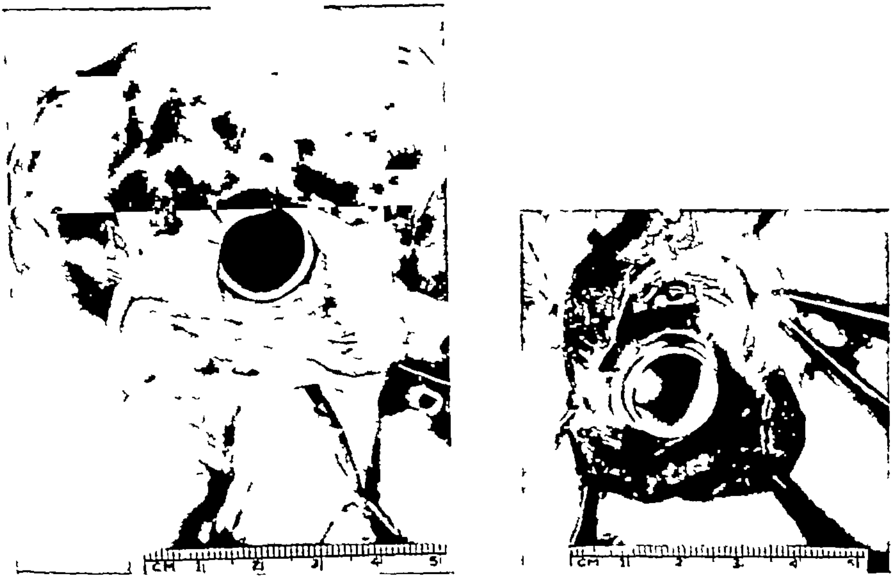

Fig 3 —Epi- and endocardial views of the shunt one year postoperatively

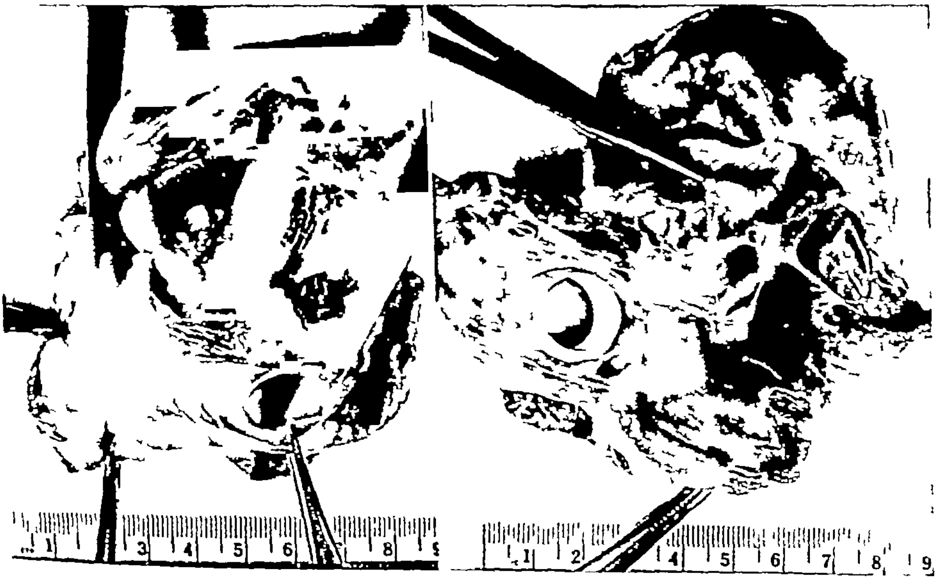

Fig 4 —Epi and endocardial view of the shunt three and one-half years postoperatively

In 2 of the 8 animals there was a 1 to 2 mm. hole in the ligated main pulmonary artery which would just admit the tip of a probe. The volume flow through these channels could not have been of functional significance. As can be surmised from Fig. 2, most of the stroke volume is ejected against the portion of the graft opposite the epicardial mouth of the tube—henceforth referred to as the "stress area." Three of 4 in Group A had stress plaques in this area, wheras at three and one half years postoperatively, only one animal had similar changes of minimal degree. Microscopically, these calcified plaques appeared cartilaginous in some sections. The early graft redundancy also disappeared in Group B, and the replacement fibrosis at the stress area caused a uniformly abrupt angulation at the epicardial mouth of the tube, which was the point of slight stenosis in the pressure studies. In 2 of the animals in Group A, a plaque appeared to project into the lumen of the vein at the juxta-cardiac portion of the tube-vessel junction where the graft was redundant. Figs. 3 and 4 show the typical one and three and one-half year shunts completely patent and completely diverting. The suture anastomoses and grafts were well endothelialized and contained healthy, cellular fibrous tissue. Note the smooth endocardial anastomoses.

DISCUSSION

The operative mortality is definitely reducible by our present technique. These decisive refinements in the endocardial anastomosis will be detailed in a later publication.

Although these dogs were not exercised on the treadmill preoperatively, experience with untrained normal dogs controls these observations. It is to be noted that their exercise tolerance did not decrease over a three-year period. Since the myocardial reserve is the important limiting factor in these runs, these data are a measure of the over-all cardiac function. The amount of work done by these animals is incompatible with any significant decrease in myocardial reserve. Furthermore, the right ventricular endiastolic and right atrial pressures are inconsistent with heart failure. Although the low diastolic pressures in the pulmonary artery evince pulmonic regurgitation, the normally low mean pulmonary-arterial pressures minimize the amount of pendulum blood in the right ventricle. The pulmonic insufficiency was probably a minor factor as compared with the stenoses of the stress area in causing the right ventricular hypertrophy recorded in Table III.[7]

The estimated myocardial hypertrophy correlates well with the heart weight/body-weight ratios calculated from Table III. Three of the ratios in excess of Herrmann's normal range (0.0060 to 0.0099) are in the animals with moderate right ventricular hypertrophy from the most marked stenoses in these shunts. The average heart-weight/body-weight ratio in these 8 animals is just within the normal range as delineated by Herrmann and others.[7, 8] Moreover, the heart weights and the heart-weight/body-weight ratios do not increase over the three-year period in this admittedly small series of cases.*

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*The average heart weight/body weight ratio in dogs is about twice that reported in human beings.[8]

Since these stenoses and other pathological lesions are almost uniformly confined to the area of the tube-vessel junction, new shunts are being constructed with homologous grafts of aortic arch in place of the vena caval homografts Curved plastic tubes are also being used to sustain the direct force of each systolic ejection These new techniques should obviate the early rupture and late stenoses in this stress area

Since it seemed preferable a priori to have a valve in the shunt, studies were pursued on the fate of the valves of venous homografts Fresh femoral-venous homografts containing one valve were sutured into gaps of divided abdominal aortas and left pulmonary arteries It was noted that clots frequently formed in the sinuses distal to the valve cusps despite permanent patency of the grafts After a few weeks the cusps adhered to the graft wall and failed to function This process along with the host replacement fibrosis renders the valve in the venous homograft of little value for long-term function Lucite ball valves have therefore been studied under systemic arterial pressures in shunts from the apex of the left ventricle to the side of the thoracic aorta Fig 5 shows a successful circumvention of the aortic valve[5] Although in this shunt, performed in 1950, the ball valve wore out in five weeks, revision of the valve subsequently has largely eliminated this problem

Fig 5—Successful by-pass of the aortic valve. Lucite ball valve in the apex of the left ventricle leads to thoracic aorta via an aortic homograft sutured end to side. Aorta proximal to this anastomosis is completely occluded

SUMMARY AND CONCLUSIONS

One- and three-year postoperative studies are reported on animals with permanent ligation of the main pulmonary artery and total by-pass of the pulmonic valve through an extracardiac shunt The shunt of plastic tube and venous homograft connects the right ventricle to the main pulmonary artery just distal to the occlusive ligature Despite the absence of a valve in the shunt, it is tolerated well, both immediately and remotely postoperatively, as adjudged by the results of treadmill runs, intravascular pressure determinations, heart weights, and other studies The relevance of this research to congenital cyanosis of cardiac origin is discussed

Acknowledgment—We are indebted to Drs S J Sarnoff, E Berglund, and A C Barger for the intravascular pressure studies

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QUANTITATIVE OBSERVATIONS DURING THE FREEZE-DRY PROCESSING OF ARTERIAL SEGMENTS

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FREEZE-DRIED arterial segments have been shown to be stable in storage for prolonged periods and to serve as acceptable blood conduits when used to bridge defects in major homologous arteries[2,3,5,13,14,17,18,19,20] Various apparatuses are currently being used to freeze-dry arterial segments We have compared the characteristics of three and are reporting the results herein These results indicate that satisfactory freeze-dried arteries may be prepared by simple techniques using suitable manifold-type vacuum systems

APPARATUS

Vacuum systems of the three following designs were studied (1) The Cryostatic Doublet† system similar to that developed by Hufnagel[14] (Fig 1) which consisted of a Cenco-Hypervac 4 mechanical vacuum pump, a length of rubber hose, oil diffusion pump, a metal connecting elbow a cold vapor trap, and a series of paired specimen traps at the bottom of which specimen tubes bearing arterial segments were attached The term "doublet" refers to a pair of joined specimen traps A Philips (ionization) gauge measured the absolute pressure in the metal elbow connecting the diffusion pump to the cold trap (2) A glass manifold and trap system (Fig 2) This consisted of a Cenco-Hypervac 4 pump, a short length of rubber hose, a glass cold vapor trap, a glass manifold bearing three standard taper joints to which specimen tubes were attached, and an absolute pressure gauge connected to the glass manifold. For purposes of this report this system is termed the glass manifold and trap (3) A brass trap-manifold system (Fig 3) This consisted of Cenco-Hypervac 4 pump connected by a short length of rubber hose to the glass outer portion of the vapor trap The inner tube of the trap was an integral part of the brass manifold. The glass outer portion of the vapor trap was jointed to the manifold by means of a brass taper joint extended as the inner tube of the trap

Combinations of these systems were also studied. The combinations involved placing a doublet in series with brass manifold extensions with and without the use of the diffusion pump in series with the mechanical pump

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†Manufactured by BiVac, 4001 Morrison Street, N W., Washington, D C

Also, we studied systems in parallel off the mechanical pump to insure identical ambient conditions in certain comparison runs The study of parallel systems was valid because the cold traps prevented cross over of water vapors from one system to the other The details of these in-series and in-parallel circuits will be described in the appropriate sections

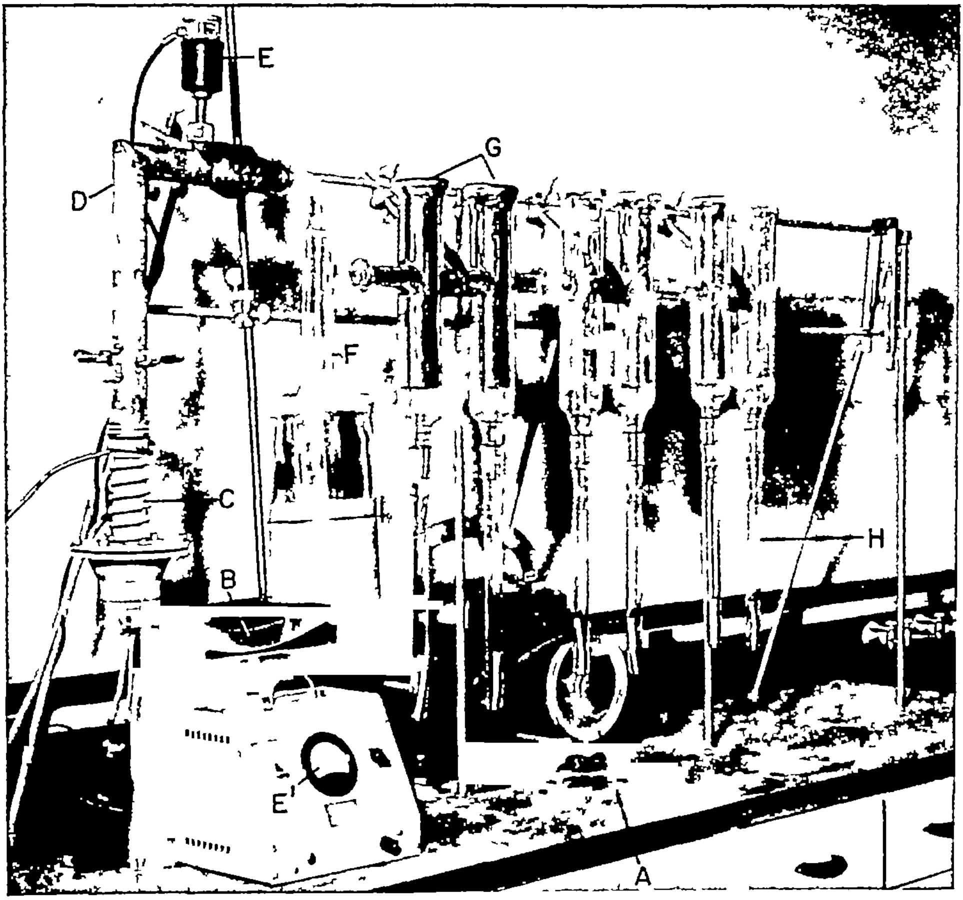

Fig 1—Photograph of the Cryostatic Doublet freeze dryer *A* Cenco Hypervac 4 mechanical vacuum pump *B* One half inch inside diameter rubber hose leading to *C* Cenco oil diffusion pump *D* Metal connecting tube *E E* Philips gauge and indicator *F* Glass trap surrounded by Dewar flask filled with coolant (dry ice or liquid nitrogen) *G* Doublet specimen traps *H* Specimen tube containing processing arterial segment

McLeod Philips and Pirani vacuum gauges were employed in this study The McLeod gauge had a range of from 1 to 5 000 microns of mercury absolute pressure The Philips gauge had a range of measurement from 1/1,000 to 1 micron of mercury absolute pressure The Philips gauge in the Cryostatic Doublet system described yielded no information as regards the water vapor pressures during the drying cycle because of its location between the cold vapor trap and the diffusion pump However, this gauge did indicate the

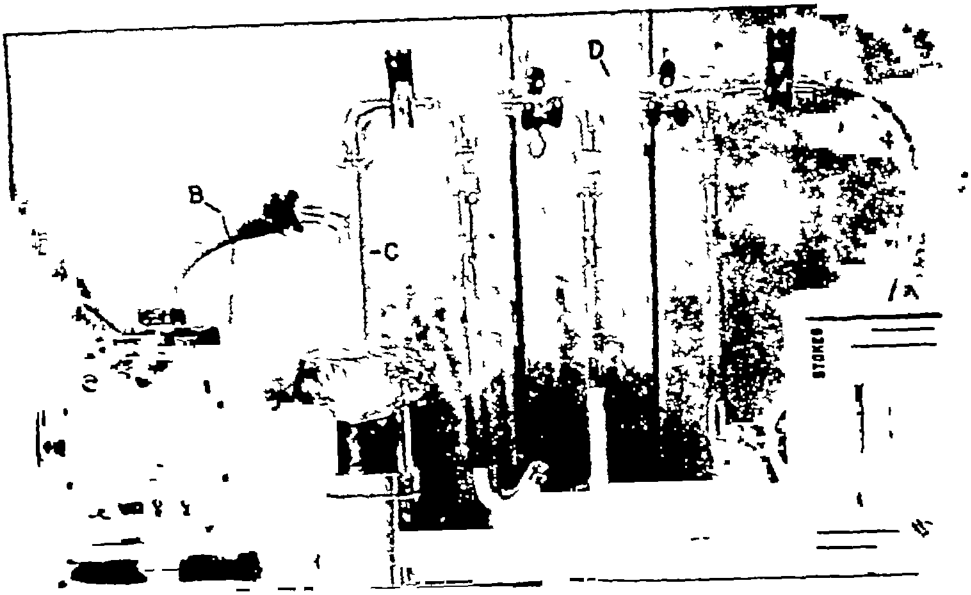

Fig 2.—Photograph of the glass manifold and trap freeze-dryer *A* Cenco-Hypervac 4 mechanical vacuum pump. *B* Rubber connecting hose. *C* Glass trap surrounded by a Dewar flask filled with coolant. *D* Glass manifold (Pyrex tubing, 1½ inches inside diameter 17 inches long) *E* McLeod gauge and indicator *F* Specimen tube containing human aortic segment.

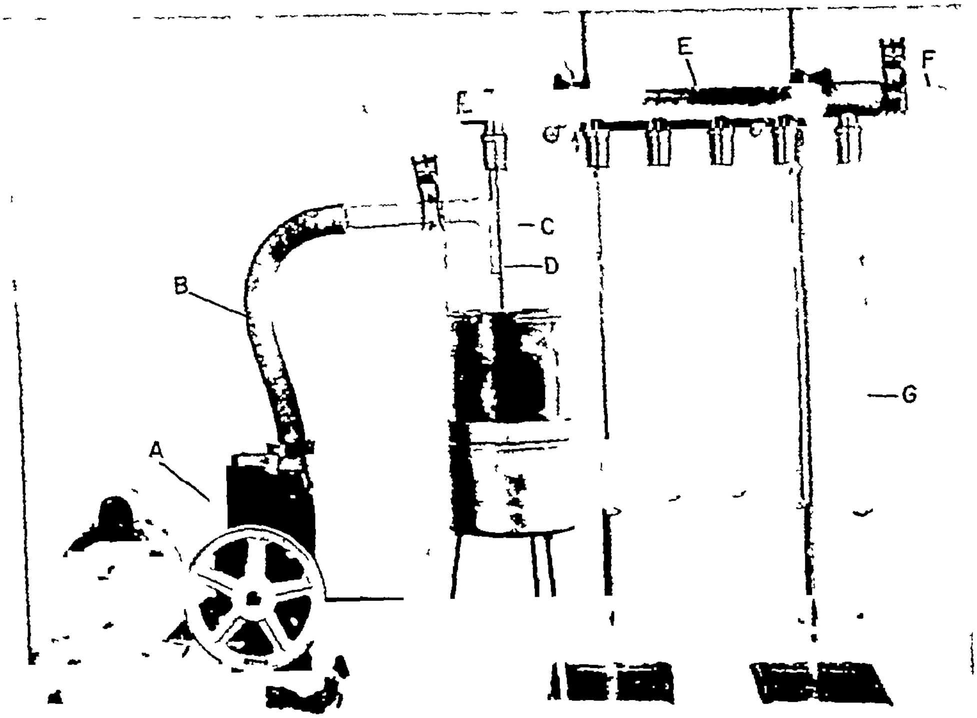

Fig 3.—Photograph of the brass trap-manifold freeze-dryer *A* Cenco-Hypervac 4 mechanical vacuum pump *B* Rubber connecting hose. *C* Glass outer tube of the vapor trap surrounded by a Dewar flask containing coolant. *D* Brass inner tube of the vapor trap which is permanently attached to the end of a standard taper joint on the manifold. *F* Brass manifold *F* Capped end of manifold *G* Specimen tube. The capped end of the manifold can be used as the attachment site of one of various gauges for the measurement of the vapor pressure during processing

degree of evacuation of noncondensable gases (air) from the system The Pirani gauge had a range of from 1 to 1,000 microns of mercury Pirani gauges were used to measure water vapor pressures at various sites within the manifolds and specimen tubes

The principle of the Pirani gauge depends upon the cooling effects of gases upon a hot wire The cooling effect for any particular gas varies with the concentration (pressure) With changes in temperature of a hot wire, there are changes in resistance These changes in resistance are calibrated in a bridge circuit involving the use of a second standard Pirani gauge The Pirani gauge pressures were constantly recorded during processing by means of direct ink writing recorders* Various gases at equal absolute pressures cool the hot wire of the Pirani gauge in proportion to the coefficient of thermal conductivity which is a constant for a given gas and is inversely proportional to the molecular weight Thus, if hydrogen, water vapor, air and argon, *each at 200 microns of mercury true pressure,* be measured by the same Pirani gauge the gauge reading will be approximately 500 microns for hydrogen, 300 microns for water vapor, 200 microns for dry air, and 100 microns for argon[1] Pirani gauges are calibrated using dry air and, therefore, when used to measure pressures of water vapor during freeze-drying will lead to readings that are falsely high as regards the true pressure On the other hand when ethylene oxide is used, the readings are falsely low since this gas has a molecular weight greater than that of argon Ethylene oxide at a true pressure of 200 microns of mercury will result in a Pirani gauge reading below 100 microns of mercury pressure When using these gauges, therefore, one must know the gas involved so that the Pirani gauge reading may be corrected to true pressure The corrected gauge reading of vapors immediately surrounding a frozen specimen is a good index of the temperature of the specimen

EXPERIMENTAL METHOD

Three types of arterial segments were used in the present study the pig abdominal aorta from the renal arteries to the bifurcation, pig thoracic aorta and the entire human aorta with attached iliac vessels

All arterial segments were prepared in a standard manner, weighed to 0 1 mg using a Fisher Gram-atic balance and then frozen in specimen tubes to the temperature of dry ice (–72° C) While the arterial segments were being prepared the vacuum system, with all ports plugged, was evacuated until a base line (constant) pressure was attained At this point the vacuum pump was stopped, the plugs removed the specimen tubes rapidly attached to the ports, and the pump restarted Dry ice was maintained about the specimens until the pressure of the system approached the base line of the dry system At this point the CO_2 was removed from around the specimen tubes and the drying cycle begun

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*Gauge manufactured by Consolidated Vacuum Corporation recorder manufactured by Brown Instrument Company

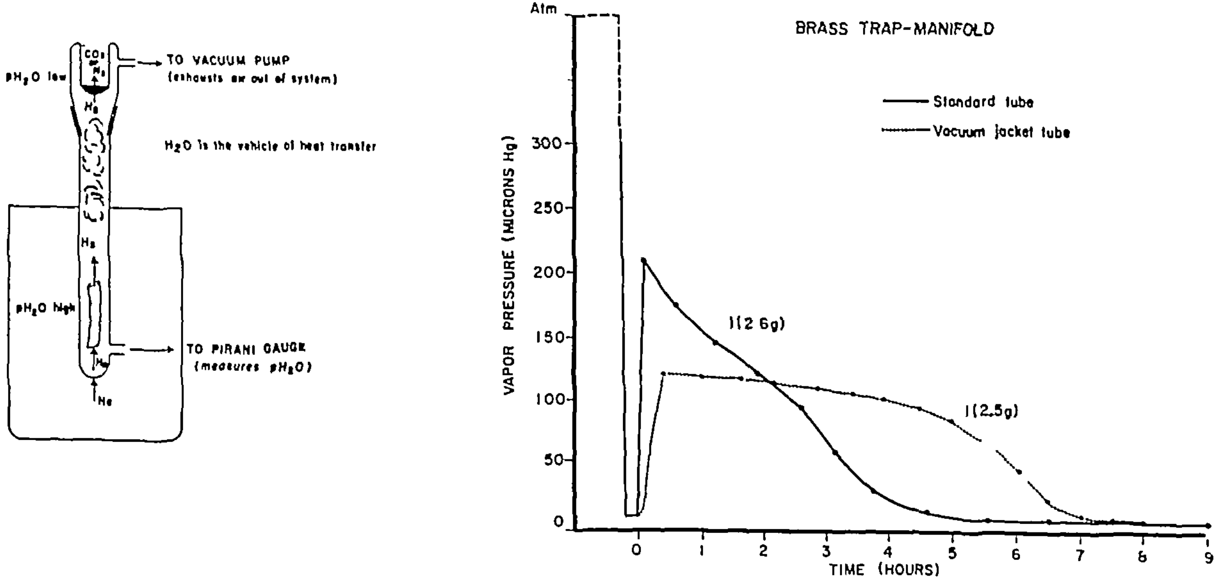
SUBLIMATION OF ICE

Before proceeding further it is advisable to review briefly the physical principles involved in the drying of frozen arteries Freeze-drying is the removal of water from a specimen by sublimation of ice under high vacuum Simple evaporation of the water from an arterial segment in a vacuum system (without prior freezing) results in a specimen which has noticeably changed physical properties upon reconstitution and which when homografted into the experimental pig has an increased susceptibility to degenerative change and late thrombosis[20] It is therefore advisable that arteries be kept frozen during processing

In order to illustrate the basic principles involved in sublimation of ice from frozen arterial specimens, a schematic freeze-dry system is shown in Fig 4 A The frozen artery is in a vacuum environment where its ice content is sublimed if the necessary heat is available from the environment The vacuum environment must be maintained for the specimen to remain frozen The vacuum is established and maintained by a mechanical vaccum pump Since most commercial vacuum pumps do not work efficiently when pumping water vapor a cold trap to desublime the water vapor, and thereby protect the pump, is included in the system Since the rate of sublimation of ice from the specimen is inversely proportional to the total pressure within the system, the higher the vacuum attained and the less leaks in the system the more rapid is sublimation A perfect system with no external leaks or internal leaks of noncondensable gases could be sealed off from the mechanical pump once the vacuum had been established and sublimation would continue until the specimen was completely dry In practice however the attainment of perfect systems is not possible and therefore, the mechanical pump must be kept in operation during the entire drying cycle

At the bottom of the specimen tube shown in the schema is a side-arm to which can be attached a Pirani gauge This gauge measures the total pressure of gases close to the specimen When the air in the system has been evacuated to the base line pressure, we can consider that the magnitude of elevation above the base line pressure is solely the result of water vapor sublimed from the specimen during processing

The ice in the specimen requires energy for the production of vapors (sublimation) This energy is supplied in the form of heat Heat is conducted from the atmosphere at room temperature via the wall of the specimen tube to the specimen One gram of ice requires 670 calories for sublimation Sublimation results in the production of an area of greater pressure of water vapor surrounding the specimen with the establishment of a gradient from this greater pressure area to the area of lower pressure of water vapor surrounding the cold trap Thus the water vapor moves from the vicinity of the specimen to the cold trap where it is desublimed This movement of water continues until there is a negligible amount of ice in the specimen, at which time it is dry


CO_2
H_2
pH_2O low
TO VACUUM PUMP
(exhausts air out of system)
H_2
H_2O is the vehicle of heat transfer
H_2
pH_2O high
TO PIRANI GAUGE
(measures pH_2O)
H_2
He
BRASS TRAP-MANIFOLD
Standard tube
Vacuum jacket tube
Atm
300
250
200
150
100
50
0
VAPOR PRESSURE (MICRONS Hg)
I(2.6g)
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0
1
2
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TIME (HOURS)

A

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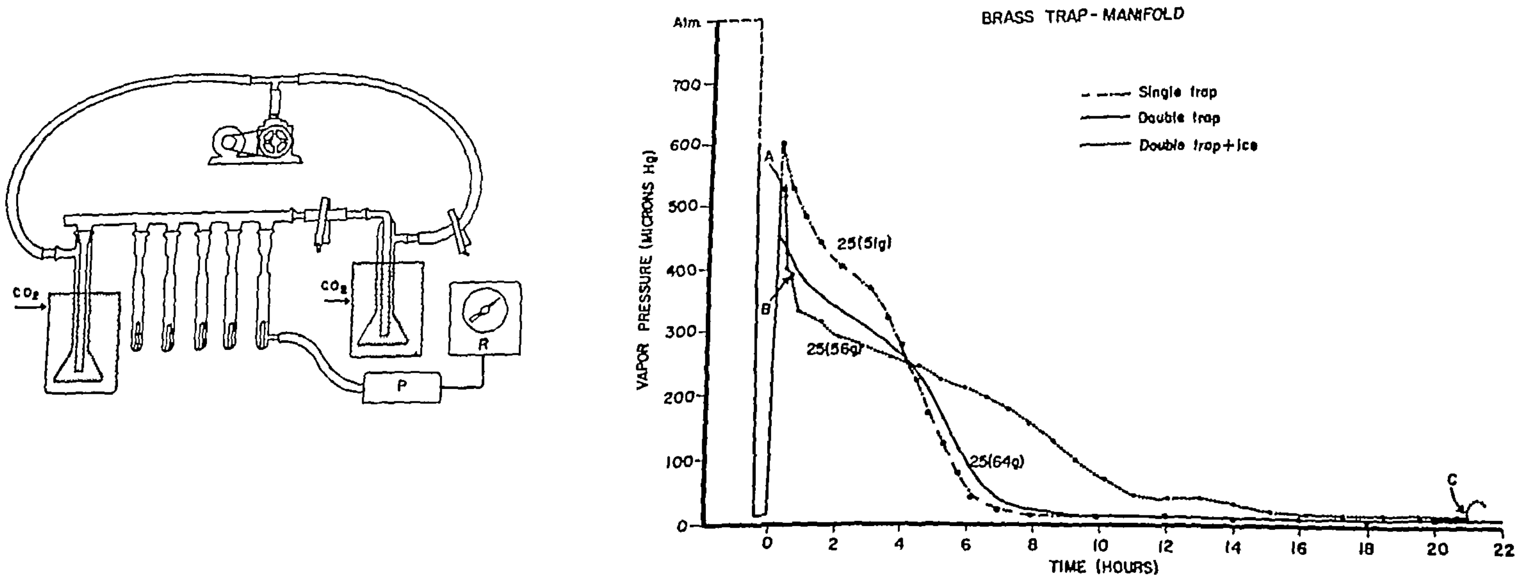

C

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Fig 4.—Aids for demonstrating certain principles of the freeze dry process *A* Schema of simplified freeze drying apparatus H_c heat of conduction H_r heat of radiation H_s, heat of sublimation CO_2, dry ice or N_2 liquid nitrogen in cold vapor trap

B, Uncorrected Pirani gauge readings plotted against time demonstrating the effect of partially heat insulating the specimen tube

C, Freeze drying system for demonstrating effect of increasing cold trap surface

D, Vapor pressure time curves obtained using the apparatus in *C* The numbers accompanying each curve represent the number of pig abdominal aortic segments used followed by the number in parentheses of grams of ice sublimed during the particular run

The temperature of the specimen during this processing is governed by the equilibrium between the amount of heat supplied to and removed from the specimen In the particular systems under consideration, the amount of heat supplied to the specimen is relatively constant since the specimen tube is exposed to essentially constant room temperature during processing The amount of heat removed from the specimen is governed by the speed with which heat is removed from the specimen as heat of sublimation, this in turn depends directly upon the speed with which water vapor surrounding the specimen is evacuated The speed with which the water vapor is evacuated depends upon the diameters of the conduits, the pressure of gases (air) in the system, the efficiency of the pump, and the temperature of the coolant in the vapor traps In general, the more rapid the withdrawal of water vapor from around the specimen, the lower the temperature of the specimen

Measurement of the peak pressure close to the specimen by means of a Pirani gauge is an acceptable index of the maximum temperature of the specimen during drying The temperature of the specimen can be estimated by comparison of the *corrected* Pirani gauge reading with the standard vapor pressure-temperature curve for ice (International Critical Tables) As a general rule, if the *uncorrected* Pirani gauge pressure at no time exceeds 300 microns of mercury, the temperature of the specimen during processing does not exceed −30° C , so long as the specimen has a significant ice content

That the heat from the ambient atmosphere influences the vapor pressure and drying time of the specimen was demonstrated with the brass trap-manifold system (Fig 4,*B*) A single pig abdominal aorta was freeze dried in a single standard tube and the vapor pressure measured in a side arm at the bottom of the tube by means of a Pirani gauge The vapor pressure drying curve is a solid black line in the graph This experiment was repeated, but another single pig abdominal aorta was placed inside of a standard tube which was surrounded by a silver vacuum jacket intended to heat-insulate the specimen in the manner of a thermos bottle It can be seen from the graph that the initial peak in vapor pressure was lower than that obtained by processing in a standard tube and that it took nearly twice as long to dry the specimen

An experiment using the system shown in Fig 4 *C* was performed in order to demonstrate that the amount of trap surface helps to prevent the occurrence of high initial vapor pressures Two traps, one at each end of the brass trap-manifold were used Dry ice alcohol mixture was used as the coolant about the vapor traps A rubber hose connecting the right end of the manifold to the trap on the right could be unclamped to include the benefit of the extra trap as desired The results of this demonstration are summarized in Fig 4,*D* With a single (left) trap the peak vapor pressure during the processing of 25 pig abdominal aortas (using 5 aortas in each of 5 specimen tubes) was 600 microns the pressure in the system returned to the base line in 10 hours When two traps were used during the processing of another 25 pig abdominal aortas, the initial peak pressure was only 450 microns of mercury implying that the maximum drying temperature was lower than when a single trap was used. The vapor pressure returned to the base line in this run in the same time as when the single trap was used. However, in the latter run 64 Gm. of water were sublimed, whereas in the first run only 51 Gm. of water were sublimed. In a third run using 25 pig abdominal aortas and a single trap, the initial vapor pressure was observed to be 510 microns of mercury. After five minutes of running, the second trap was allowed to function in the circuit (point A on Fig. 4 D) with an immediate drop of vapor pressure to 400 microns of mercury. The system was allowed to proceed for another 15 minutes. Cracked ice at 0° C. was placed about the specimen tubes (point B on Fig. 4 D) and maintained for a period of 20 hours. It is apparent from the vapor pressure curve of this run that the ice surrounding the specimen tubes delayed heat from entering the specimens and thereby delayed drying. With removal of the ice from about the tubes after 21 hours, a rise in vapor pressure occurred indicating that the specimens were not completely dry. (If dry ice at −72° C. had been maintained about the specimen tube, no drying of the specimen could occur since the vapor pressures in the vapor trap and about the specimen would be equal, resulting in a zero gradient of water vapor pressure.[8])

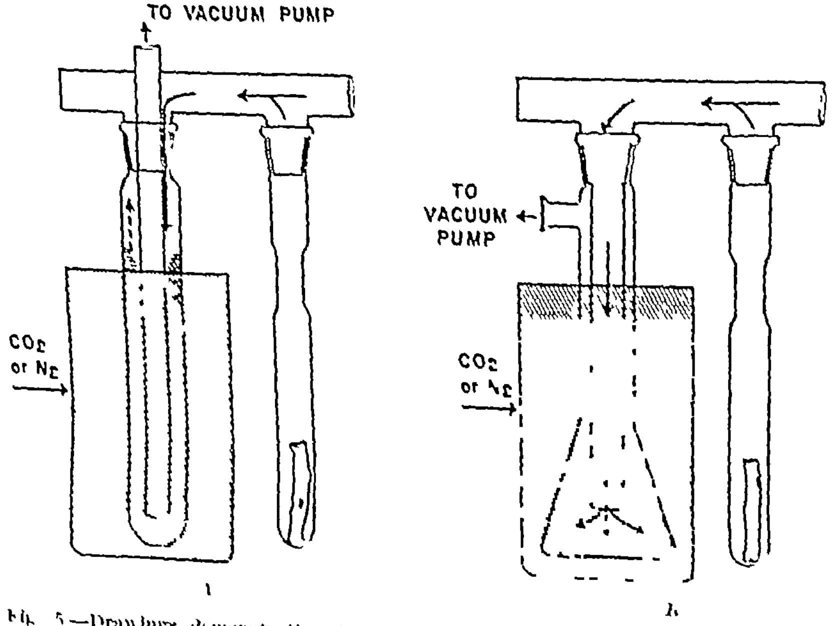
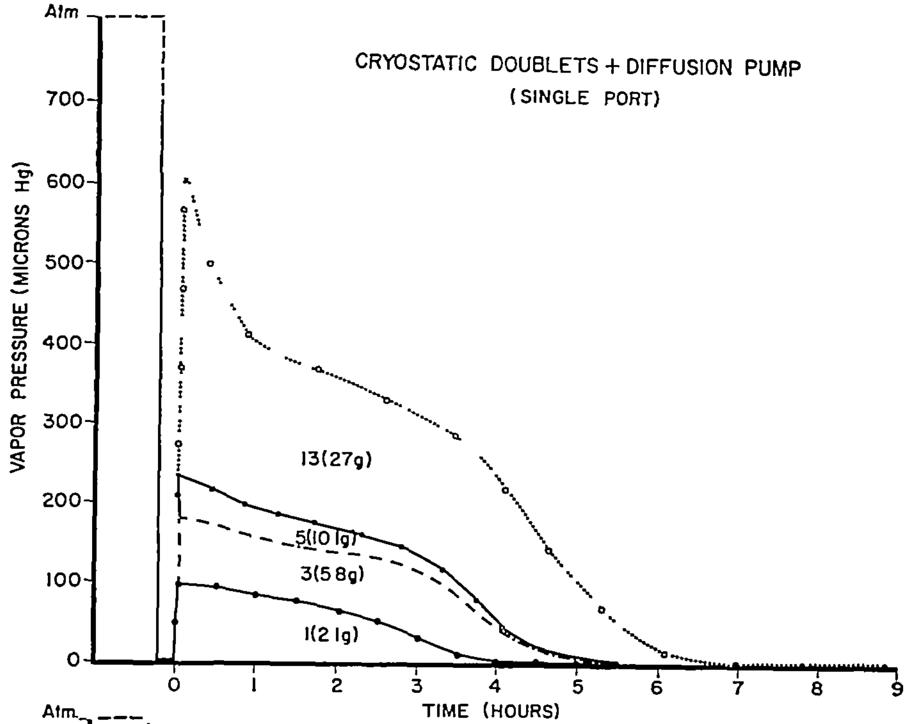


Fig. 5.—Drawings demonstrating the details of trap design. CO_2, dry ice; N_2, liquid nitrogen. Arrows depict the movement of the water vapors during processing. *A*, Improper design. *B*, Proper design.

In considering the design of cold vapor traps, two factors must be kept in mind. (1) The trap must have sufficient capacity so that it can mechanically contain all the water in the form of ice that is to be removed from the specimen. Calculation of the amount of water contained can be easily done



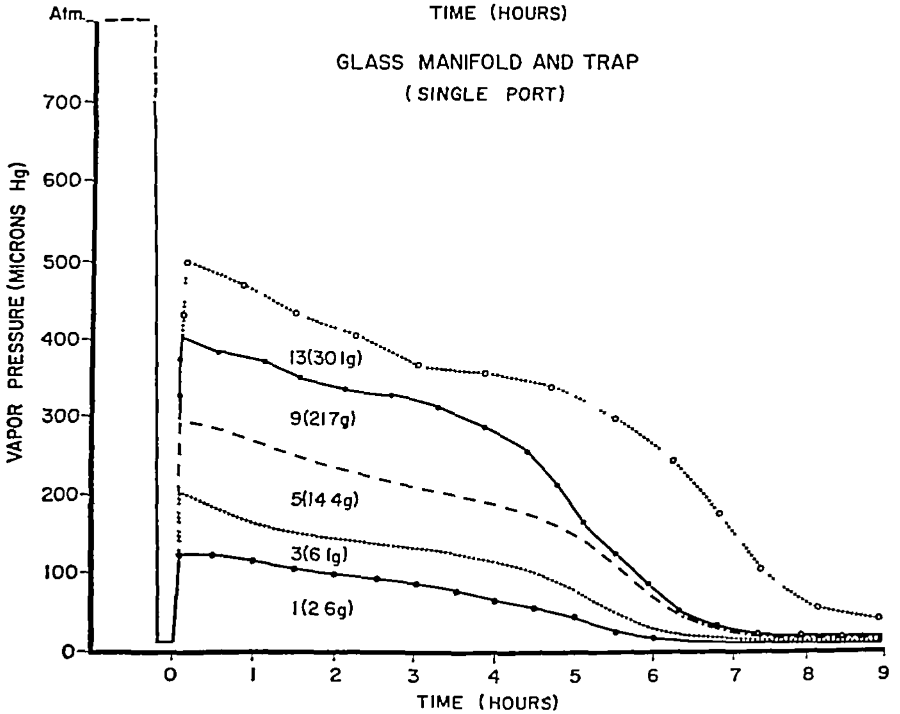


Fig 6.—Vapor pressure time curves comparing the uncorrected Pirani gauge readings in the Cryostatic Doublet and glass manifold and trap systems during the processing of various loads of pig abdominal aortic segments Accompanying each curve are 2 numbers the first represents the number of aortic segments used and the number in parentheses indicates the weight of ice sublimed from this particular load after processing to a final moisture content of 1 per cent or less

since both human and pig arteries contain about 80 per cent of water, most of which is removed during the freeze drying process To increase the mechanical capacity of the cold vapor traps for our experiments, we have found it convenient to have the bottom of the cold vapor trap constructed of a 500 ml Erlenmeyer flask, as illustrated in Fig 5,*B* (2) The trap itself should lead the vapors from the manifold system directly into the bottom of the trap where they can be desublimed Proper design is illustrated in Fig 5,*B* Improper design is illustrated in Fig 5,*A* where the vapor from the system is led into the trap external to the inner tube of the trap Under the latter conditions the vapors condense at the level of the coolant that is used to surround the cold vapor trap In such a design, especially when liquid nitrogen is used, as the level of the coolant drops slightly, the condensed vapors resublime and feed vapors back into the system to interfere with the evacuation of water vapor from around the specimens The design in Fig 5,*B* necessitates that the coolant be nearly empty in the container surrounding the cold trap before any vapor feedback into the system can occur

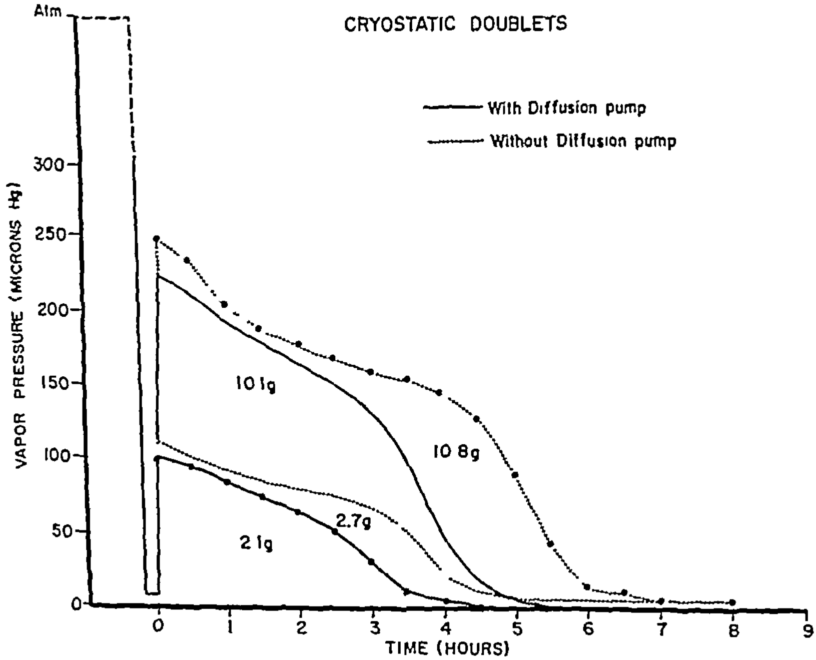


Fig 7—Graph comparing uncorrected Pirani gauge readings using the Cryostatic Doublet system with and without the diffusion pump The number accompanying each graph indicates the grams of ice removed by complete processing of each load

VAPOR PRESSURE STUDIES[*]

Continuous vapor pressures were measured at the specimen level by recording Pirani gauges during the entire drying cycle in the three basic systems described Liquid nitrogen and dry ice-alcohol traps were used in the Cryostatic Doublet and glass manifold systems, respectively In different runs,

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[*] Uncorrected Pirani gauge readings are used in the graphs throughout this communication

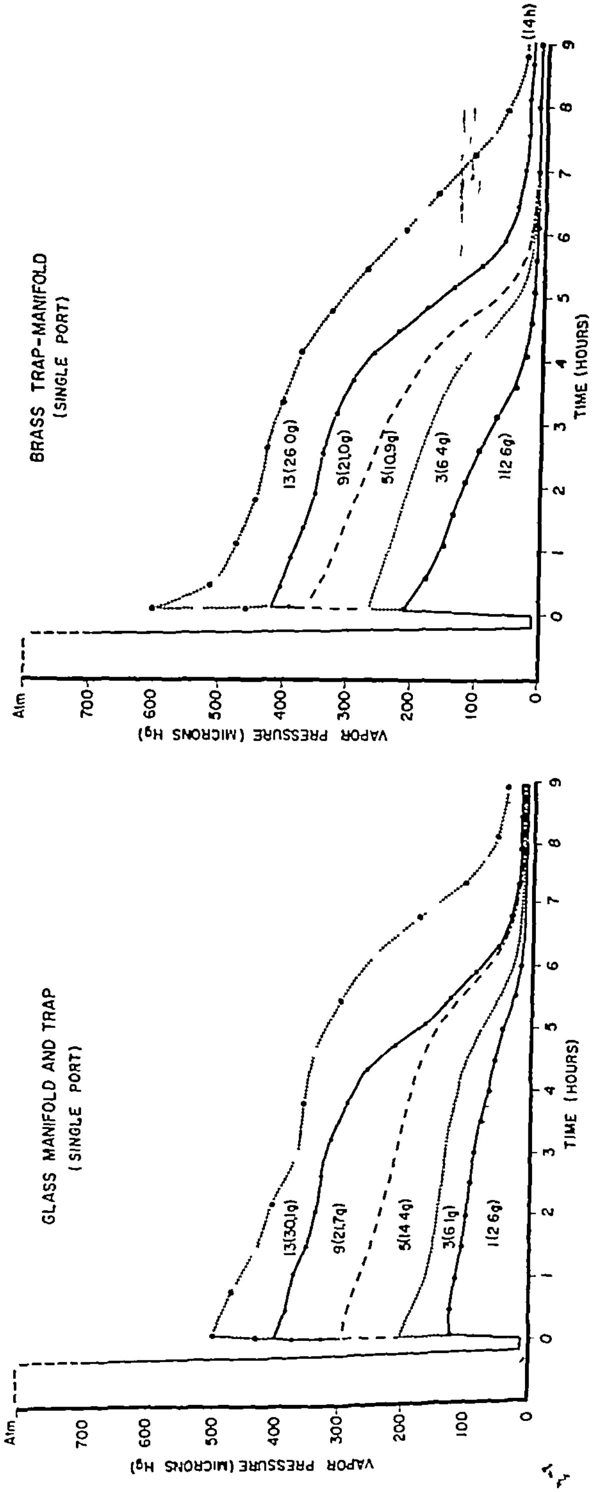

Fig. 8 (For legend see opposite page.)

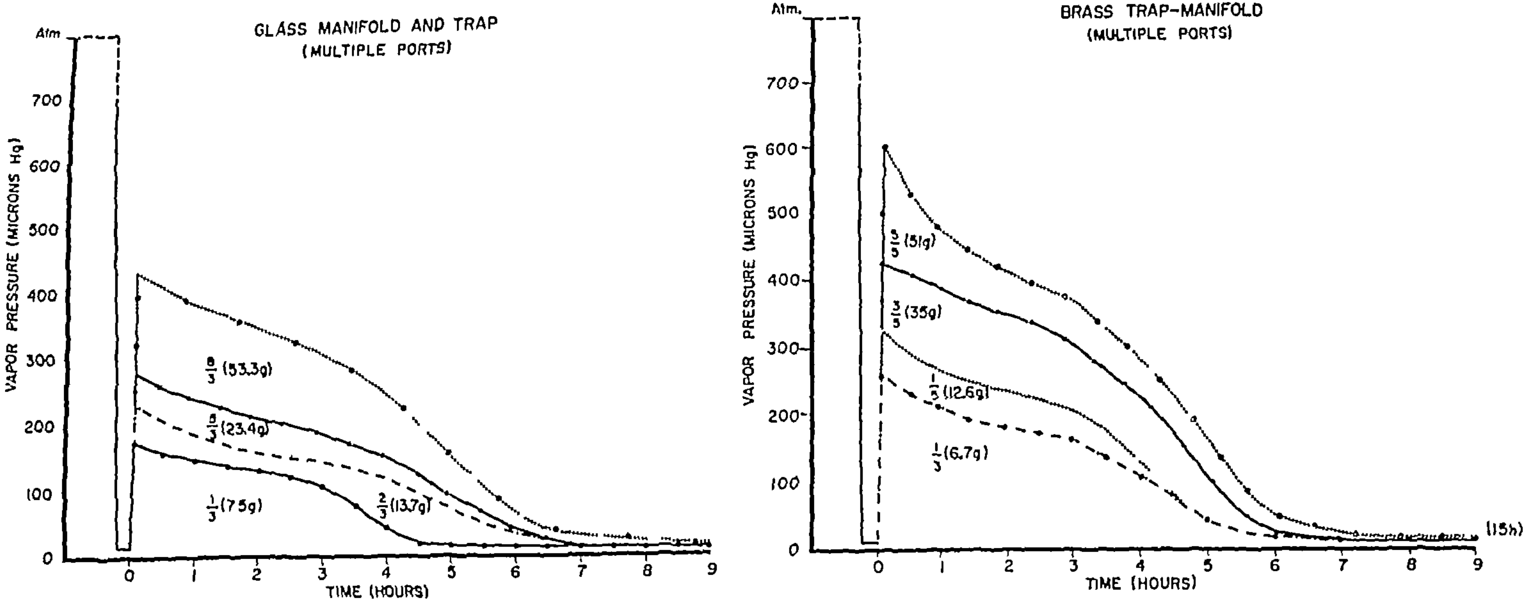

FIG. 8.—Uncorrected Pirani gauge readings obtained during the processing of various loads of pig abdominal aortic segments in a single specimen tube and in multiple specimen tubes using the *glass manifold and trap* and the brass trap manifold systems. The numbers accompanying each curve in the single port graphs refer in sequence to the number of aortic segments used and the grams of ice in parentheses sublimed from these segments after reduction of the water content to 1 per cent or less. The numerator of the fraction accompanying each curve in the *multiple port* graphs indicates the number of aortic specimens in each tube (port) and the denominator indicates the number of tubes (ports) used. The parenthetical numbers indicate the *grams of ice sublimed as above*.

the number of pig abdominal aortas in a single tube was varied from one to thirteen. The results obtained in these runs are summarized in Fig. 6. For either system, the smaller the load, the shorter the drying cycle. Comparison of the two families of curves shows that for any given load of vessels the peak vapor pressure and drying time in the Cryostatic Doublet Diffusion pump system was generally less than that in the glass manifold and trap system. The load which corresponds to the maximum load that a single tube would be expected to carry in the freeze-drying of human vessels would be the curve referred to as 5 pig abdominal aortas (10 to 15 Gm. of water). The results of another experiment summarized in Fig. 7 demonstrate that it is probably the diffusion pump which makes the difference between the two systems. In this experiment the same Cryostatic Doublet was used to process two different loads. One load consisted of a single pig abdominal aorta which contained about 2 Gm. of water, and the other load consisted of three pig abdominal aortas, which contained approximately 10 Gm. of water. Each load was processed with and without the diffusion pump. As can be seen from the graph there was very little difference in the peak vapor pressure with and without the diffusion pump. However, after two hours in the 2 Gm. water load and after three hours in the 10 Gm. water load there was significant divergence of the vapor pressure curves, resulting in a demonstrated significantly shorter drying cycle when the diffusion pump was used. However, there was very little difference in the maximum temperature of the specimens during processing as evidenced by the peak vapor pressures. The vapor pressure curves obtained using the Cryostatic Doublet system without the diffusion pump are quite similar to those of the same loads using the glass manifold and trap system as illustrated in Fig. 6. Therefore, it is believed that the inclusion of a diffusion pump has the only advantage of shortening the drying cycle, but leads to no significantly safer temperature of the specimen during the processing.

Vapor pressure studies comparing the efficiency of the glass manifold and trap system with the brass trap manifold system are summarized in Fig. 8. Dry ice-alcohol was used as the coolant about the traps in all runs that are plotted. In other runs the use of liquid nitrogen instead of dry ice alcohol as the coolant did not influence the vapor-pressure curves. The graphs compare the vapor-pressure curves for varying loads on a single port in each system and also for varying the load on multiple ports in each system. In the single port studies, the tube was placed upon the port furthest from the cold trap and the vapor pressure measured in a side arm at the bottom of the tube. In the multiple port studies, all ports were used and the vapor pressure measured in a side arm at the bottom of the farthest from the cold trap. It is to be noted that for any given load in the single or multiple port graphs the initial vapor pressure attained in the glass manifold and trap system was slightly lower than that in the brass trap manifold system, implying that the temperature for any given load was slightly lower in the glass manifold and trap system. However, the differences in drying temperatures were not significant. From comparison of the vapor-pressure curves, it can be seen that for any given load of ice to be sublimed the lower vapor pressures are attained if the load is divided into multiple specimen tubes All three systems that is the Cryostatic Doublet system the glass manifold and trap system, and the brass trap-manifold system are adequate The manifold systems, however require slightly longer processing

WEIGHT STUDIES

The reduction in water content as the drying cycle progressed was determined in each of the four systems illustrated in Fig 9 These systems were I A series system of a mechanical pump a diffusion pump a cold vapor trap surrounded by liquid nitrogen coolant, one doublet and two brass manifold extensions, each bearing six ports Liquid nitrogen was used in the specimen trap of the doublet II The system is identical to that in I with the exception of deletion of the diffusion pump III The standard Cryostatic Doublet system as previously described consisting of a mechanical pump, a diffusion pump, a cold trap and three doublets in series Liquid nitrogen was used in each of the specimen traps in the doublets and also as the coolant around the cold vapor trap IV The brass trap-manifold system, as previously described, with a brass extension bearing six extra ports The results using either liquid nitrogen or carbon dioxide-alcohol mixture around the trap were identical in the latter system

For the various runs the number of tubes and the location of the specimen tubes were as indicated (Fig 9) Standard pig abdominal aortas were used in these runs In all but one run the load was constant one pig abdominal aorta in each of four specimen tubes However, in one run using System II one doublet port and ten of the in-series manifold ports were used Each tube in this case contained two arteries These vessels dried along the same curve of percentage weight loss as those in runs involving only four tubes with one artery per tube

Loss of water from the specimens with time was determined as follows In System III the specimen tubes were sealed off at 1, 2, 4 4½ 5, and subsequent hours after initiation of the process In Systems I II, and IV, the pump was stopped at intervals and the specimen tubes on each run were disconnected from the system, the specimens were weighed rapidly upon a Fisher Gram atic balance to 0 1 mg accuracy The total time between interrupting a particular run and the weighing of the last specimen did not exceed six minutes The specimens were then refrozen in a mixture of CO_2 and alcohol, placed back on the system, the system was re-evacuated, and the run was continued The time of processing was corrected for the period of interruption Following the last interruption for any particular run, the tubes were placed back on the system and the system was evacuated until the vapor pressure regained the level prior to the final interruption, at this point each tube was sealed off All tubes were then stored

The final moisture content was determined on 99 freeze dried arterial segments by a modification of the technique of the National Institutes of Health[11, 24] Ninety specimens were pig abdominal aorta segments and nine

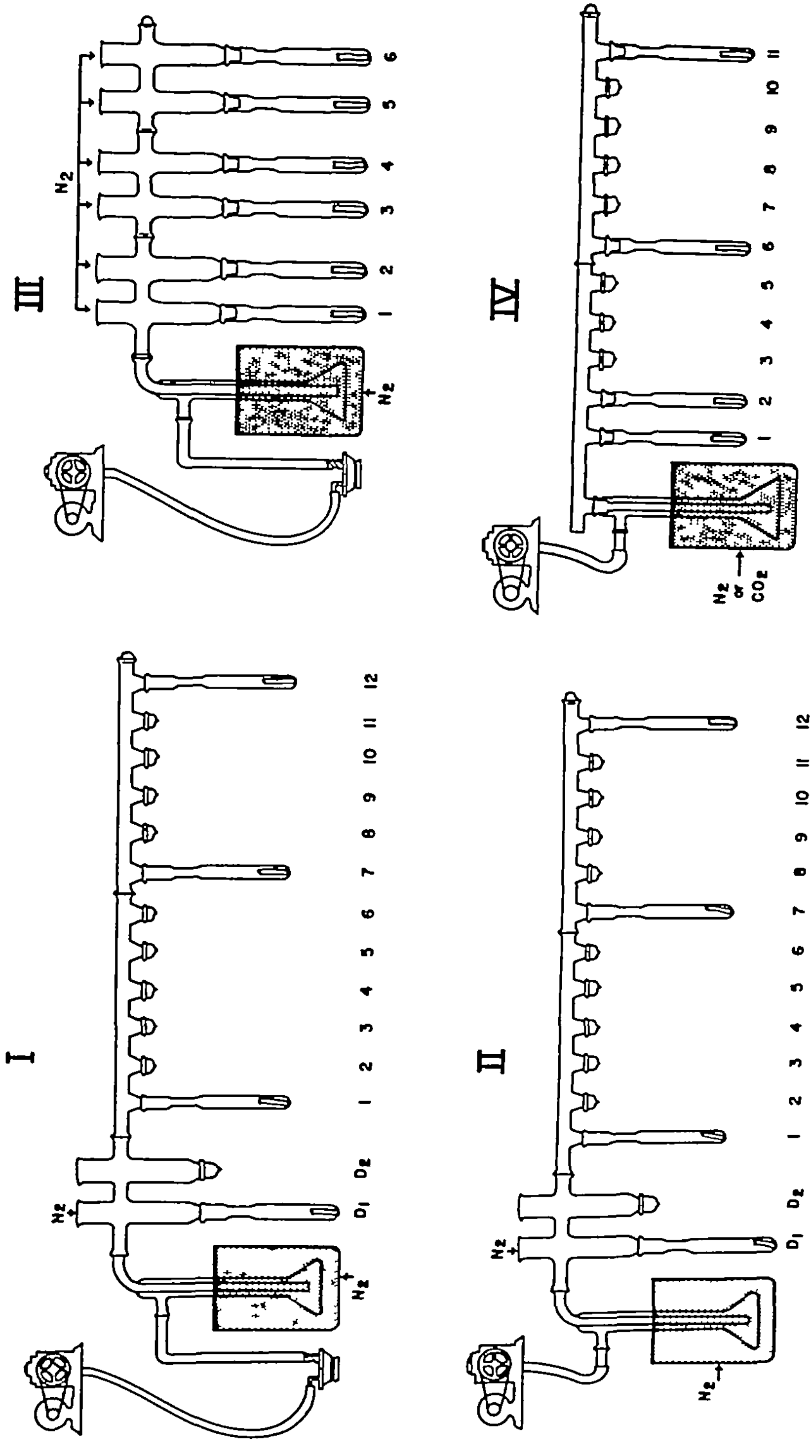

Fig. 9.—Schematic drawing of the four freeze drying systems used to obtain the data in Fig. 10. (See text for details.)

were human aorta segments No weighing bottles were used The apparatus was housed in a large air-tight lucite box measuring 30 by 24 by 18 inches A Fisher Gram atic balance, capable of weighing grams to the fifth decimal place, and desiccator jars were contained within the box Shoulder length rubber gloves were attached in air-tight manner to two ports at the front of the box To secure a moisture-free atmosphere, large Petri dishes containing phosphorus pentoxide were placed in suitable locations within the box, and, during weighings, super-dry nitrogen was allowed to flow into the box at a rate of from 12 to 18 L per minute A small hole in the top was used to hand specimens into the box, and also to provide a vent for the super-dry nitrogen In the conduction of the moisture determination, the specimen which was sealed in a glass tube in its primary vacuum, was removed after hot-wire fracture of the specimen tube The specimen was quickly handed through the hole in the top of the box and was immediately weighed It was then placed in a desiccator jar At the bottom of the desiccator jar was a Petri dish filled with fresh phosphorus pentoxide A stainless steel screen protected the top of the Petri dish A stainless steel plate bearing numbered holes was suspended 1 inch above the screen Each specimen was placed on end into a numbered hole Thirteen to fifteen specimens were loaded into a single desiccator jar The loaded desiccator jar was covered and evacuated to a pressure of 50 microns of mercury At this point the desiccator jar was sealed Forty-eight hours later the jar was opened and the specimens were re-weighed to determine water loss They were replaced in the desiccator jar in early determinations and re-weighed at 96 hours It was noted that there was no further loss in the second 48 hour period Thus, in subsequent determinations, only one weighing was done at 72 or 96 hours Four specimens were also sent to the National Institutes of Health for moisture determinations* Their results were in very close agreement with ours

Using the final weight of the moisture determination (after 72 to 96 hours of desiccation over fresh phosphorus pentoxide in a vacuum of 50 microns of mercury) as the dry weight (zero water content) of the artery, it was a simple matter to compute the weight of water per specimen at a given time of interruption by subtracting the final weight of the specimen from the observed weight of the specimen at the given time of interruption This weight of water divided by the observed weight at the given time of interruption multiplied by 100 was taken as the water content of the specimen at this specific time The water content was thus computed for each specimen at each interruption Water contents were plotted against time for the various systems, I, II, III, IV It was found that the initial water content of all arteries averaged 80 per cent (range from 75 to 83) Fig 10 shows that there was remarkably little scatter in all observations and that the rate of water loss was approximately similar for the four different systems The curves of Groups I and II were so similar as to be represented by a single line Group III showed the most rapid weight loss of the four systems, reaching a moisture

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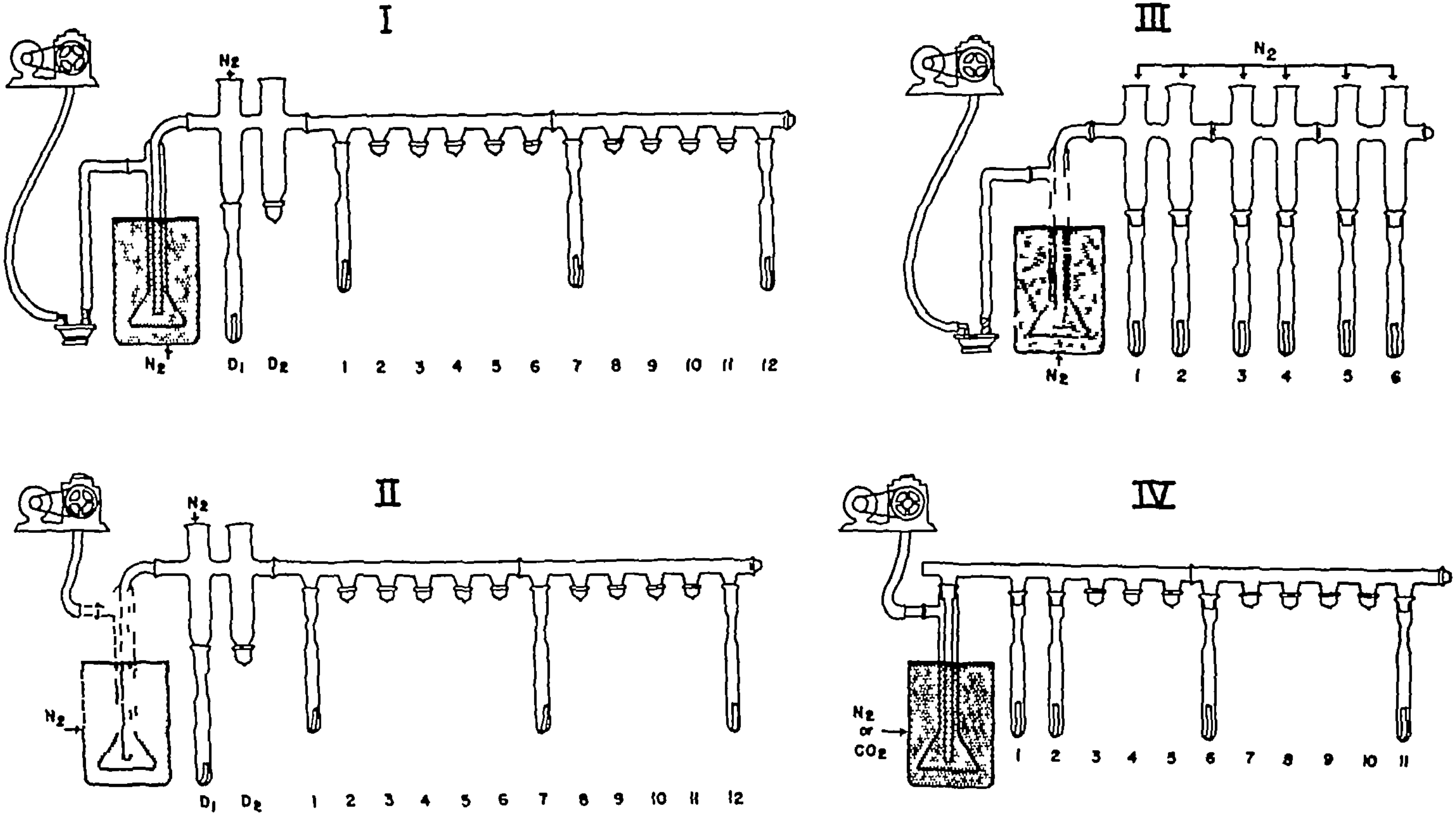
*Conducted through the courtesy of Drs G Workman T F Probey and H W Burrows of the Biologics Control Laboratory National Institutes of Health



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content of 1 per cent (removal of 99 75 per cent of original water content) after six hours of processing In the other three groups the moisture content after 6 hours of processing was approximately 2 per cent (removal of 99 5 per cent of original water content) reaching the 1 per cent level at some time between 9 to 12 hours of processing These times of reduction of the specimen to 1 per cent final moisture content are uniformly 1 to 2 hours longer than the time it takes the vapor pressure in these various systems to return to the base line pressure In laboratory practice either the 6 hour or 12 hour time of processing is acceptable In our opinion, exclusion of the diffusion pump for processing of reasonable loads on the systems described is justified because (1) its use does not significantly affect the drying temperature, and (2) its use involves significant added difficulties of procedure

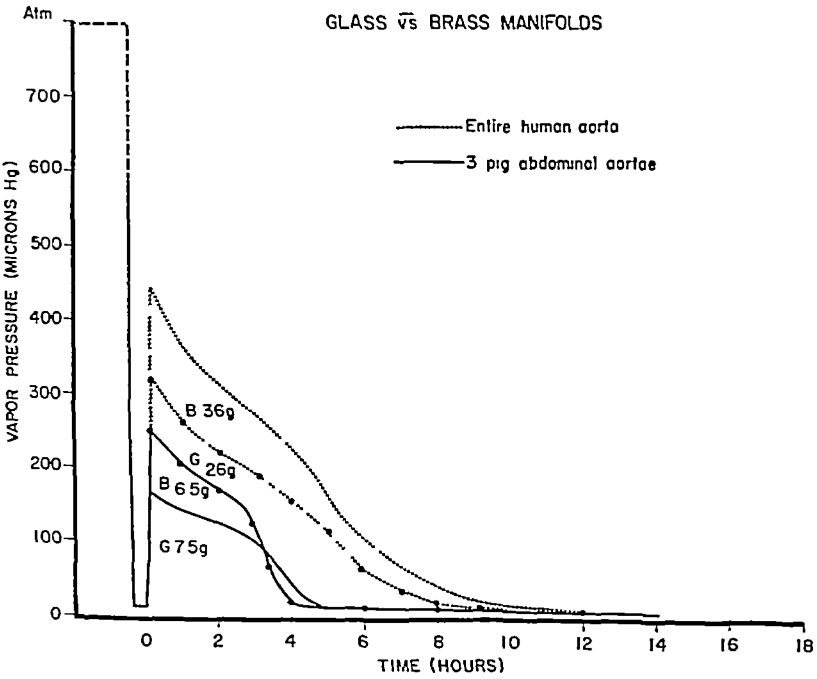

Fig 11—Graph illustrating the uncorrected Pirani gauge readings obtained during the processing of a standard load of three pig abdominal aortas and of a segmented human aorta and comparing the results when using the glass manifold and trap freeze-dryer *G* and the brass trap-manifold freeze-dryer *B*

FREEZE-DRYING OF HUMAN VESSELS

Special studies were done during the processing of several human aortas Fig 11 summarizes the results of one of these experiments On the plot the letter "B" refers to processing by the brass trap-manifold, and the letter "G," by the glass manifold The numbers accompanying each graft represent the amount of water which was removed from the specimen during the processing The two lower plots are the vapor-pressure curves obtained by the processing of three pig abdominal aortas, one in each of three specimen tubes Vapor pressures were measured through a side-arm at the bottom of the tube farthest from the cold vapor trap The vessels in both of these systems were processed simultaneously, the glass and the brass systems having been in parallel to the mechanical pump The two top curves in Fig 11 summarize the vapor pressures during the processing of human aortas For each system the entire human aorta was divided into three tubes as follows The aortic arch was placed into a special arch tube,[20] the remainder of the thoracic aorta was placed into a straight tube, and the abdominal aorta and iliac vessels to the inguinal ligaments were placed as a single specimen into another straight tube The aorta processed on the brass manifold was obtained at a routine autopsy and was relatively free of disease The aorta processed in the glass manifold was sterile and subsequently banked The tubes were attached to the ports so that the aortic bifurcation was in the tube farthest from the trap Uncorrected peak vapor pressures for the glass and brass systems were 320 and 450 microns, respectively, estimated corrected values were approximately 225 and 300 microns, respectively This implies that the maximum drying temperature of the specimens on the glass manifold was approximately –33° C and that in the brass trap-manifold was approximately –30° C The drying cycle was of approximately the same duration in both systems

ETHYLENE OXIDE STUDIES

All data thus far presented were obtained using untreated arteries The use of ethylene oxide for the sterilization of grafts as introduced by Hufnagel[14] is becoming more widely accepted Its use increases the supply of human homograft material by permitting nonsterile procurement of specimens Quantitative observations of the influence of ethylene-oxide treated arterial segments upon the freeze dry process were made

A preliminary experiment with human aortas was done using two brass manifolds with dry-ice traps in parallel with the same mechanical pump The aorta attached to one of the brass manifolds was treated with ethylene oxide as described by Hufnagel*, the aorta on the second brass manifold was untreated A McLeod gauge was used to register the pressure at the end of each brass manifold When processing was begun, it was noticed that the vapor pressure in both systems became greater than 3,000 microns of mercury and the specimens partially thawed The reason that the pressure in the manifold bearing the untreated arteries rose to such a high level is that the ethylene oxide being removed from the treated specimens was not condensed at the temperature of the dry-ice trap, as the freezing point of ethylene oxide is –111° C Maass and Boomer[16] demonstrated that ethylene oxide forms a chemical hydrate with a freezing point slightly above 0° C Ethylene oxide hydrate is apparently unstable as a gas so that during the sublimation of the hydrate, ethylene oxide is liberated, necessitating condensing coolants at temperatures below –111° C Liquid nitrogen (boiling point of –196° C) is adequate as the coolant for this purpose

A series of four experiments were then done to quantitate the effect of ethylene oxide treatment upon the vapor pressures during processing In all of these experiments liquid nitrogen was used as the trap coolant These experiments are summarized in Fig 12 All experiments utilized the brass trap-manifold and a standard load of three pig abdominal aortas in a single specimen tube Vapor pressures were recorded via a side-arm on the bottom of the specimen tube using the Pirani gauge and recorder The vacuum system was pre-evacuated with all ports plugged and a base line reading of approximately 7 microns was noted in each experiment. The standard load in each of the four runs was frozen in a dry ice-alcohol mixture, attached to the end port of the brass trap-manifold and the specimen tube was surrounded by dry ice The system was then re-evacuated In the first experiment, no

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*Ethylene oxide kindly supplied by Dr Charles Hufnagel Georgetown University Medical Center

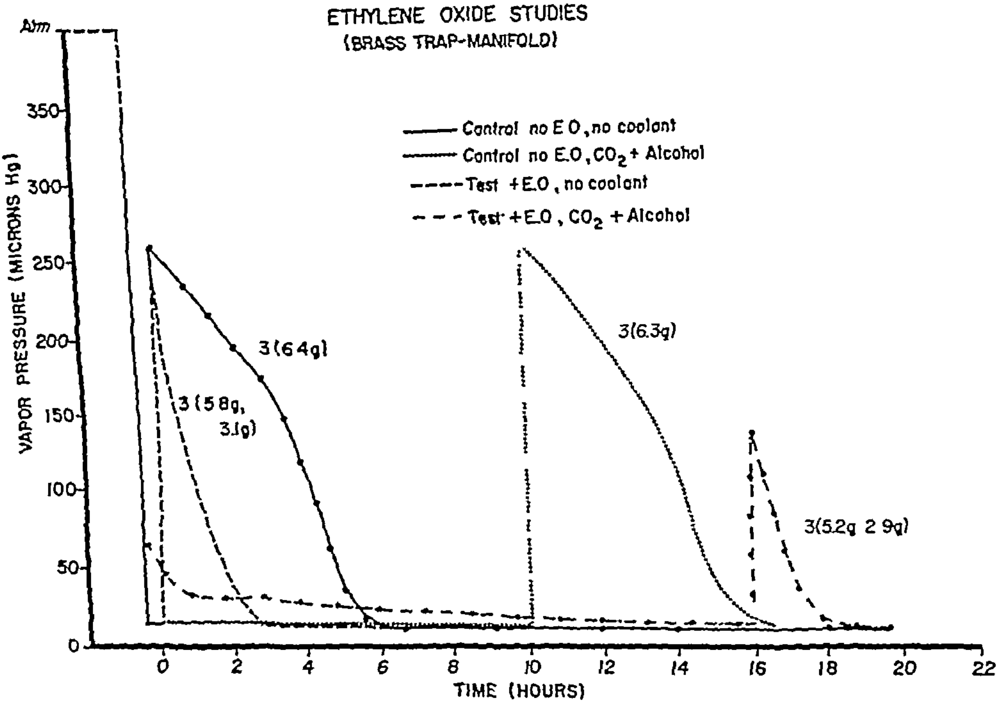

Fig 12—Graph summarizing the uncorrected Pirani gauge readings obtained during the freeze-drying of a standard load of three pig abdominal aortas under varying conditions of pretreatment. Accompanying the curves of control runs the numbers in parentheses indicate the grams of ice removed during processing The first parenthetical number accompanying the curve of each test run indicates the total grams of water removed from the load (initial weight minus final weight) and the second parenthetical number indicates the weight subsequent to ethylene oxide treatment. The difference between these two parenthetical numbers represents the amount of weight loss as the result of ethylene oxide treatment alone

ethylene oxide treatment was done The dry ice was kept about the specimen tube until the system was evacuated to its base line of 7 microns at which point the coolant was removed from around the specimen tube There was a rapid rise of the vapor pressure to 270 microns of mercury The vapor pressure then followed the expected decay cycle, reaching the base line of the system in approximately 7 hours In the second experiment, no ethylene oxide was used but the CO_2 alcohol mixture was maintained about the specimen tube for a period of 10 hours After 10 hours the carbon dioxide was removed from around the specimen tube. The vapor pressure subsequently followed a pattern quite similar to that of the first experiment. In the third experiment the specimens were pretreated with ethylene oxide. As a result of the treatment with ethylene oxide, the specimen was found to lose 2.7 Gm. or approximately 50 per cent of its original weight. The dry ice was removed from around the specimen tube 3 minutes after the mechanical pump was started. The vapor pressure rose from 60 microns to 240 microns of mercury. The vapor pressure in this experiment was observed to follow an accelerated rate of decline, reaching the base line in approximately 5 hours. In the fourth experiment, the specimen was treated with ethylene oxide, and the dry ice was allowed to cool the specimen tube for 16 hours of processing. In contrast to the control, which was not treated with ethylene oxide and which was dry iced for 10 hours, during this experiment the vapor pressure remained elevated above the base line. This implied that even with carbon dioxide and alcohol around the specimen tube, significant vapor pressure was exerted by the treated artery. After 16 hours of processing, the coolant was removed from around the specimen tube and there was noted a rapid rise in vapor pressure to the level of 135 microns of mercury. This demonstrated that the specimen was not completely evacuated of volatile materials (water, ethylene oxide and/or ethylene oxide hydrate). But the fact that the vapor pressure did not rise as high as in the noncooled ethylene-oxide-treated specimen indicates that during the 16 hours of cooling partial drying had occurred. It should be stressed that these vapor pressure readings are uncorrected Pirani gauge readings. Corrected readings imply that the untreated specimens had a maximum drying temperature of approximately -35° C. and that the ethylene oxide treated specimen without coolant had a maximum drying temperature of at least -26° C.

The results of experiments in which untreated human aortic segments were freeze dried in parallel with ethylene-oxide treated human aortic segments demonstrate that drying is accelerated in ethylene oxide-treated vessels. After 15 hours of processing the untreated segments had a 1.5 per cent final moisture content whereas the ethylene oxide treated segments had a final moisture content of 0.3 per cent.

It is suggested that arteries sterilized by this method should be rapidly frozen immediately after the ethylene oxide is decanted in order to prevent drying by evaporation with consequent protein denaturation.[9b]

BETA-PROPIOLACTONE STUDIES

There has been recent interest in the use of *B* propiolactone as a sterilizing agent for human arterial segments to be used subsequently as grafts.[19] A 1 per cent solution is recommended. *B*-propiolactone is a relatively volatile liquid having a freezing point of -33° C.[21] A 1 per cent solution, however, has a freezing point close to 0° C. A group of 6 experiments using a standard load of pig thoracic aorta were performed. There were no differences in the vapor pressure curves and duration of drying cycle during processing of the untreated and the

B-propiolactone-treated vessels Dry-ice and liquid nitrogen traps were equally effective The three systems (doublets, glass manifold, and brass manifold) were once again shown to be practical equivalents

DISCUSSION

The critical temperature at which an artery must be maintained during sublimation is not known For cytological work, Scott[22] has found that a temperature of –32 5° C is practical It has been shown that above the temperature of –20° C ice crystals are indeed large and are destructive to the normal microscopic architecture of tissues, whereas ice crystals formed below –30° C are much smaller and do not significantly distort architecture Microscopic sections of pig abdominal aorta processed in this study at maximum temperatures of –30° C and fixed in the dry state in formalin exhibit no significant architectural distortion Further it has been shown that blood vessels stored for prolonged periods in the frozen state at –27° C are inferior when used as grafts to those which have been stored at –70° C[4] Although no definite observations have been made as regards the critical drying temperature during the freeze-drying of arterial segments, one can say empirically that it is safe, if the temperature of the specimen does not rise above –30° C until the specimen is nearly dry

Ice crystals in the specimen can be large if the arterial segments are slowly frozen Therefore, specimens should be quickly frozen prior to processing Immersing the specimen within its tube in a mixture of dry ice and alcohol represents sufficiently rapid cooling[14, 20, 25] Once the specimen in its tube is at the temperature of the dry ice-alcohol mixture (as evident by no further bubbling around the tube), it is attached to a port of a freeze-drying apparatus, the vacuum pump is begun, and the processing starts

Sewell and Koth[23] suggest that arterial segments with final moisture contents of 5 per cent may prove more satisfactory upon grafting than segments dried to 1 per cent or less final moisture content However biological products (e g , diphtheria antitoxin) with moisture contents of 5 to 8 per cent completely lose their potency after a few weeks of storage[8] Flosdorf states "In no case should a moisture above one per cent be allowed if the product is to be stored for more than a few months, particularly when not under refrigeration" Reduction of the moisture content of such sensitive physicochemical systems as plasma egg albumin, and complement to less than 0 5 per cent results in no changes in electrophoretic pattern or immunologic activity after years of storage at room temperature[10] Until definite proof to the contrary is presented, we assume that drying to a final moisture of 1 per cent or less leads to a biological product of optimal stability and minimal denaturation

It is our opinion that the Cryostatic Doublet-diffusion pump system represents the ultimate in design for the freeze-drying of arterial segments but that the manifold systems tested in the present study are easier to operate less expensive, and practically as efficient

For practical purposes an "overnight run" with average loads, using any one of the three systems described in this communication, will reduce the water content of arterial segments to 1 per cent or less If measurement of the vapor pressure of the specimen side of the cold vapor trap is not feasible or if an individual is otherwise in doubt, a 24-hour period of processing should suffice In loading specimens into tubes one must guard against jamming arteries into the bottom of the tube If there is not space between the wall of the arterial segment and the wall of tube, at least along one side, there is danger of melting of the bottom of the specimen during processing It is also advisable for vessels to be processed rounded rather than collapsed

SUMMARY AND CONCLUSIONS

1 The principles of the freeze drying have been reviewed

2 Three variations in design of free-dry apparatus (Cryostatic Doublet-diffusion pump, glass manifold and trap, and brass trap manifold systems) have been compared by quantitation of vapor pressure-time curves for various loads of adult pig abdominal aortas and human aortas These systems with loads not exceeding 20 Gm of ice per port are practical equivalents

3 Data supporting the following conclusions have been presented

a The drying temperature of average loads (e g, entire human aorta in three tubes) varies from –30° to –35° C

b The use of a dry ice alcohol mixture (–72° C) as the coolant about the vapor trap is as effective as liquid nitrogen (–196° C) when processing untreated vessels However, if ethylene oxide is used to sterilize the arteries, dry ice-alcohol is contraindicated as the trap coolant, liquid nitrogen is adequate in these circumstances

c The inclusion of a diffusion pump in the vacuum system shortens the drying cycle but does not significantly affect the drying temperature of arterial segments during processing It is our opinion that an adequate mechanical pump alone is sufficient for practical laboratory processing

4 Processing continued for 2 to 4 hours after the vapor pressure on the specimen side of the cold trap returns to the base line level results in arteries with a final moisture content of 1 per cent or less

5 It is recommended that specimen tubes *containing ethylene oxide* treated vessels be kept surrounded by a dry ice alcohol mixture during the first hour or two of processing Treated vessels undergo some drying at –72° C whereas untreated vessels exhibit no drying at –72° C

6 Treatment of arterial segments with 1 per cent *B*-propiolactone prior to freeze drying does not affect the vapor pressure time curves during processing

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KARTAGENER'S SYNDROME REPORT OF A CASE TREATED BY PULMONARY RESECTION

Review of the Literature

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HISTORICAL DATA

In 1933 Kartagener[35] described a syndrome characterized by bronchiectasis, situs inversus totalis, and rhinopharyngosinusopathy This author accepts as the etiology of the morbid triple association the fact that it is the expression of congenital malformations of varied localization, some at the level of the respiratory tract (lung, rhinopharynx, sinuses) and others at the level of the whole visceral complex (situs inversus totalis)

Actually the first mention of the condition was given by Siewert[62] who, in 1904, reported the case of a 21-year-old man, in whom the three elements of the syndrome were present, this was followed by Oeri's[52] necropsy findings in 1909 and later, in 1923, Guenther's[31] report, where he reports the case of a 19 year old woman and points out the fact that the patient's sister also presented symptoms of total visceral transposition Moreover, this author emphasizes the infrequency of situs inversus as its incidence in 63,377 patients registered at Leipzig Institute of Medical Clinics reached only 0 007 per cent

Although these reports precede Kartagener's chronologically, to this author was left the merit of the interpretation and etiological correlation of the different components of the syndrome, that had undoubtedly escaped the attention of those who believed they were describing a mere morbid casual association Kartagener explained his theory in successive reports,[35, 36, 37] gathering a total of 11 cases in 1935

REVIEW AND DISCUSSION

In a careful review of the world literature, we have found 104 cases reported, 8 of which were published by Argentine authors

The most important series have been reported by Olsen[54] and by Torgensen[63, 64] who have published 14 cases each, Kartagener and Horlacher[35, 36, 3] have reported 11 cases, Adams and Churchill,[14] 5 cases, Lopez Areal,[42] 4 cases, Conway,[26] 4 cases, Neumann,[50] 3 cases, Brügger,[22] 3 cases, Nussel and Helbach,[51] 2 cases, Jacob, Langle, and Langle,[33] 2 cases, Allende and Langer,[2] 2 cases, Chattas, di Rienzo, and Piantoni,[4] 2 cases, Russakoff and Katz,[55] 2 cases The reports of isolated cases have been made by Siewert[62], Oeri[52], Guenther[31],

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Berhman[19], Kautzky[38], Aguilar, Nijensohn, and Guaglianone[1], Casaubon and Derqui[3], Klopstock[40], Wernli-Haessig[66], Lilienthal[41], Flick[28], Churchill[23], H Meyer[44], F Meyer[43], Glaum[30], Jedlicka and Petrikova[34], Becker[18], Rosenthal[58], Cole and Nalls[25], Nagy[49], Murray[48], Adland and Einstein[15], Oettli[53], Richard[57], Delp[27], Benda and Huet[20], Weill, Lallemant, and Leveque[65], Andrews[17], Langer[6], Blixenkrone-Moller[21], Alves Meira and Ferreira[16], Fraga Filho, Nery, and Maranhao[29], Kay and Meyer[39], Zuckerman and Wurtzebach[67], Dassen and Gotlieb[5]

Of the mentioned authors, the cases in which operation was performed were reported by Lilienthal (left lower lobectomy), Flick (right lower lobectomy), Ingraham (lobectomy on both sides), Churchill (middle lobe lobectomy and left lower lobectomy), and Allende and Langer (lobectomy in three cases)

There are arguments both in favor of a common congenital origin of the three elements of the syndrome of Kartagener and in favor of a mixed etiology—congenital and acquired—of bronchiectasis and rhinosinusopathy

Savé[61] and Meyer[44] have found bronchiectasis in twins, Pastore and Olsen[55] have discovered bronchiectasis and absence of frontal sinuses in identical twins, Kay and Meyer[39] observed Kartagener s syndrome associated with an anomalous left subclavian artery Weill, Lallemant, and Leveque[65] described another case, in which the patient's brother presented a congenital malformation of the heart of the ' Fallot type ' Cockayne,[24] studying the etiopathology of visceral transposition, could prove its presence in members of different families related in various ways In the cases observed by him, visceral malformation was not associated with bronchiectasis Kautzky[38] mentioned three cases of situs inversus totalis in which no bronchial dilatation was present Other authors as Nüssel and Helbach,[51] Behrman,[19] Benda and Huet,[20] and Oettli,[53] who dealt specifically with Kartagener's syndrome, supported a mixed etiology and divided it into congenital predisposition and acquired infection

In 1937, Adams and Churchill[14] reported 5 cases and analyzed the experience at the Massachusetts General Hospital, where, in a total of 232,112 patients registered, 712 were bronchiectatic and 23 presented visceral transposition, of the latter, 5 had Kartagener's syndrome The authors pointed out that 21 7 per cent of the patients with situs inversus totalis had bronchiectasis and rhinosinusopathy while only 0 3 per cent of the total number of patients registered presented these affections

Olsen[54] analyzed the experience at the Mayo Clinic, where, in 22 years, 85 cases of total visceral transposition have been observed, 14 of which have presented bronchiectasis and rhinosinusopathy The frequency of bronchiectasis in relation to the total number of patients registered was 0 5 per cent, while in patients with situs inversus, they appeared in 16 5 per cent Such statistical data made them favor the existence of a congenital factor

Russikoff and Katz[59] mentioned two cases and made a review of the world bibliography until 1946, finding only 50 cases reported Without saying anything definite as to etiology, they pointed out the frequency with which patients with situs inversus present bronchiectasis, saying that it is advisable to search for the condition in all cases of visceral inversion

Lopez Areal[42] made a careful study of the subject reporting four cases. Torgensen[43, 44] found 14 cases of Kartagener's syndrome in 129 visceral transpositions, 123 of which were total and in 8 per cent were accompanied by nasal polyposis. The coincidence of situs inversus and bronchiectasis in several members of a family, is, according to him, an argument in favor of a common congenital origin for both affections. In 1951, Conway[26] reported 4 cases and advocated congenital etiology. In the same year, Zuckerman and Wurtzebach[illegible] reported another case.

CASE REPORT

G. M. E., 21-year-old male laborer. Admitted Nov. 6, 1953.

Familial and Personal History.—Unimportant.

Present Disease.—Began during early childhood with episodic catarrh of the respiratory tract, after which a permanent mucopurulent bronchorrhea appeared. Periodic impairments during winter. He obtained only temporary relief upon symptomatic treatment. Mucopurulent nasal secretions. He had had no hemoptysis. At the time of hospitalization he had 200 c.c. of mucopurulent expectoration, mainly during the morning and in left lateral decubitus.

Physical Examination.—*a*, Respiratory tract: moist râles with medium and large bubbles in both lower pulmonary fields, more marked and abundant in the right side where there was also a syndrome of hypoventilation, "sounds" of secretions in trachea and larger bronchi. *b*, Abdomen: hepatic dullness to the left, and tympany of the Traube space to the right. Cecal gurgling in the left iliac fossa and palpation of the ileosigmoid in the right iliac fossa. *c*, Cardiovascular examination: complete dextrocardia with aortic arch to the right, and descending aorta to the left. ECG: see Fig. 1. Rhinolaryngologic examination: intense edema and diffuse congestion of all the pharyngeal and nasal mucosa, the latter with purulent exudates, marked hypertrophy of the lymphatic elements with mucosa of localized polypoid aspect, veiled paranasal sinuses with no signs of acute sinusitis in activity (Fig. 6); external bilateral otitis.

Laboratory Data.—Slight hypochromic anemia (red-cell count, 3.7 million per cubic millimeter). Repeated acid fast bacilli investigations in sputum: negative. The remaining examinations were normal.

X-Ray Examination.—Fluoroscopy of the thorax: complete inversion of the cardiovascular silhouette, heart apex, pulmonary arch and aortic notch to the right; remains of Lipiodol in both pulmonary fields corresponding to previous bronchographies. Gastric bubble to the right, the left hemidiaphragm was two fingerbreadths higher than the right one; normal diaphragmatic movement, hepatic shadow to the left (Fig. 1). (See Figs. 2 to 9, inclusive.)

Bronchoscopy.—Mucopurulent secretions in the basal bronchi where the mucosa was red and swollen.

Functional Exploration of the Lungs.—Ventilatory reserves: 90 per cent; the maximum breathing capacity and the vital capacity corresponded to a 70 per cent and an 85 per cent respectively, of the theoretical figures. Broncho spirometry, the left lung (placed in the right hemithorax) showed a 32 per cent hematosis and a 23 per cent ventilation Oximetry arterial blood (femoral artery) saturation was 95 8 per cent in rest and exertion.

Diagnosis—Situs inversus totalis, bilateral bronchiectasis with right predominance, chronic hypertrophic rhinopharyngosinusitis, external otitis

Preoperative Treatment—A hygienic dietetic regimen was established, parenteral and aerosol antibiotics, vitamin therapy, hepato-ferrotherapy, postural drainage, exercises, respiratory re-education, and treatment of the rhinopharyngosinusitis by a specialist This treatment was carried out for 7 months, at the end of which time the clinical situation of the patient was as follows he had gained 17 kilograms in weight, was in excellent general condition, had a normal red-cell count and blood-volume, and the expectoration had been reduced from 200 c c daily to 50 c c , and the septic foci in upper respiratory tract were controlled It was decided to undertake the resection of the more affected pulmonary segments (right side, left lung)

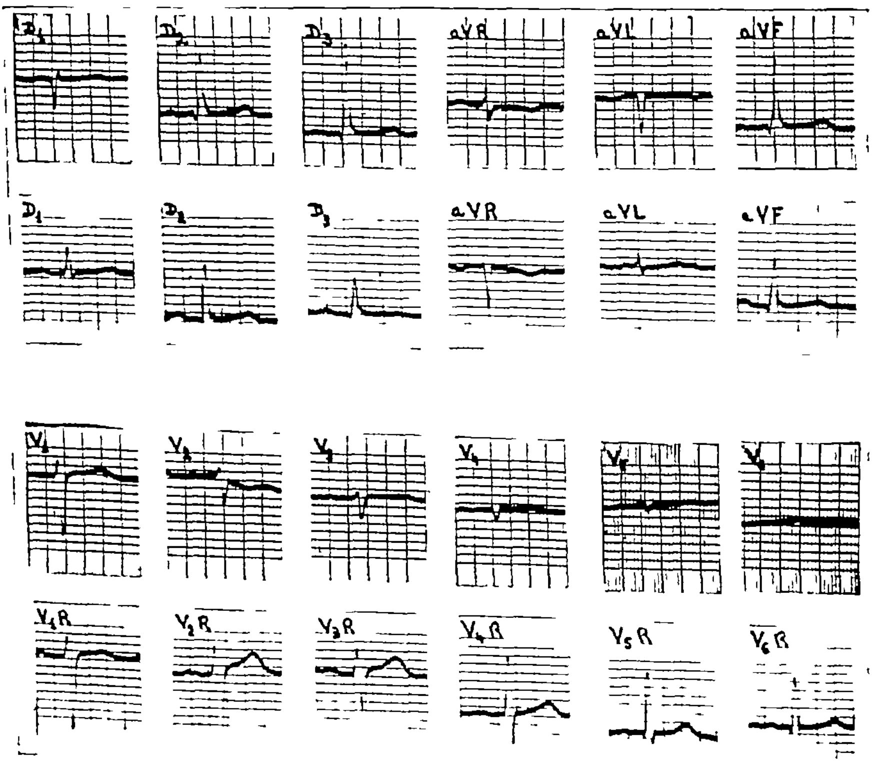
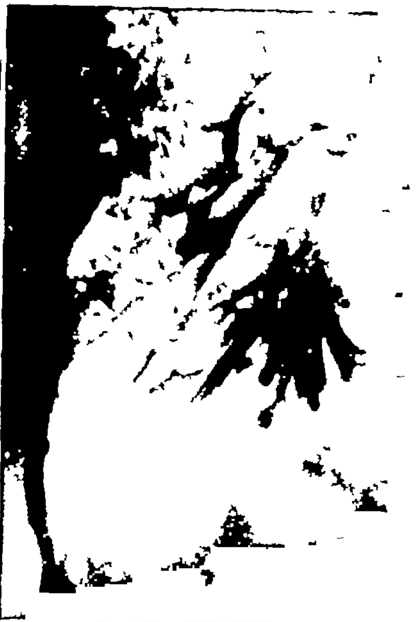


Fig 1—The schema corresponding to the superior rows of both groups belongs to an ECG obtained with the classical technique. The one situated in the inferior part of both groups corresponding to an ECG taken with inversion of the cables of the upper limbs placing points of the precordial single poles on the right hemithorax ECG diagnosis complete dextrocardia with total positional inversion of the cardiac cavities

Operation—May 21, 1954 General anesthesia with endotracheal intubations Pentothal curare, intravenous Novocain were used In left lateral decubitus a right posterolateral thoracotomy was performed with pleurotomy through

Fig 2

Fig 3



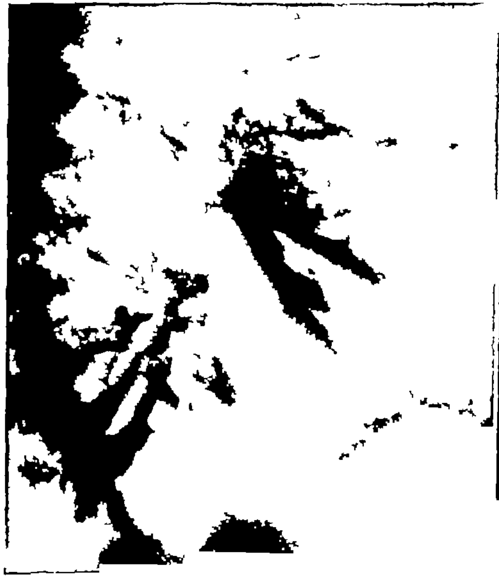


Fig 4

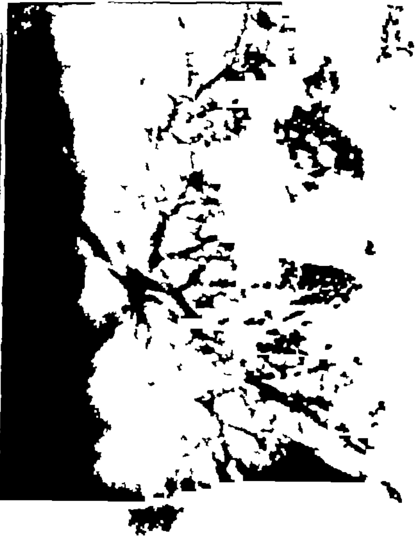


Fig 5

Fig 2—Confirms what had been observed in fluoroscopy complete inversion of the cardiovascular silhouette heart apex bulge of the pulmonary artery and aortic notch to the right remains of Lipiodol in both pulmonary fields gastric chamber to the right hepatic shadow to the left the left hemidiaphragm is two fingerbreadths higher than the right one

Fig 3—(Right bronchography) Large cylindrical and saccular bronchiectasis of the lower lobe the lingula and the anterior segment of the upper lobe It should be noticed that although it is the right hemithorax the bronchial pattern corresponds to a left lung The gastric chamber is shown with an hydroaerial level

Fig 4—(Right bronchography lateral view) Confirms what has been observed in the frontal bronchography showing the involvement of the anterior segment of the upper lobe of both lingular bronchi and of the basal bronchi of the inferior lobe.

Fig 5—(Left bronchography) Small cylindrical bronchiectasis of the basal bronchi It must be noted that although it is the left hemithorax, bronchial pattern is typically right also the shadow corresponding to the liver can be observed

the fifth space, pleura partially adhered Anatomy corresponded exactly to that of a left hemithorax, two-lobed lung with complete fissure heart apex pulmonary artery aortic arch and thoracic aorta placed in this hemithorax No major azygos vein Typical lower lobectomy was first performed then followed by lingulectomy and anterior segmentectomy of the upper lobe with dissection

Fig 6

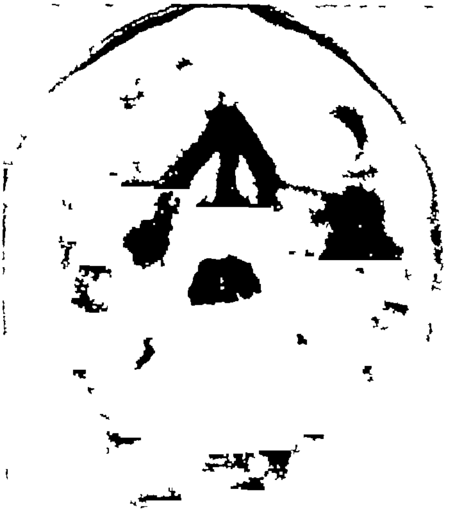
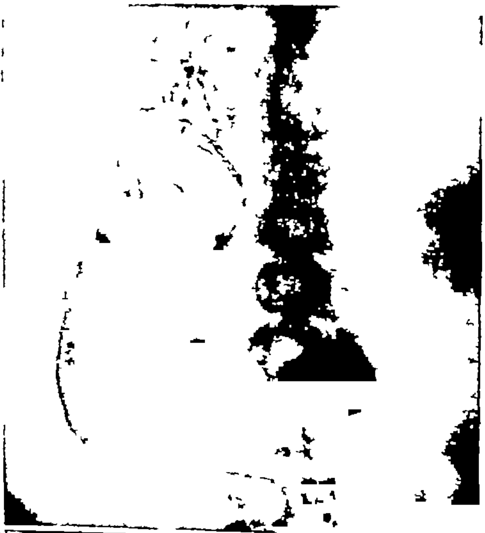


Fig 7



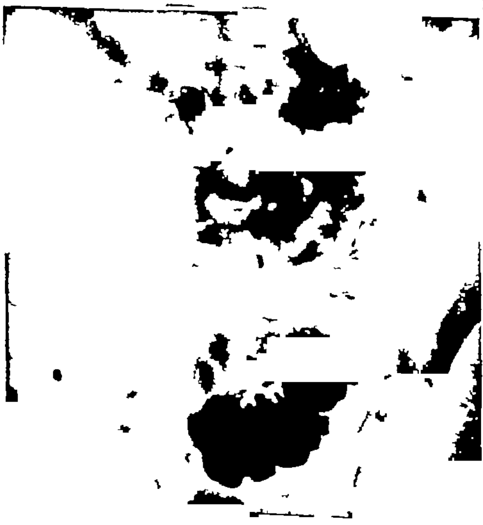


Fig 8

Fig 9

Fig 6—Slight diffuse veiling of paranasal sinuses

Fig 7—Completely inverted arrangement of the stomach and the duodenal frame to the left the shadow corresponding to the liver

Fig 8—(Twenty four hours after barium ingestion) The filling of the cecum and of the ascending colon in left arrangement is observed part of the opaque mixture has reached the transverse and the descending colon rest of barium mixture is in the small bowel The splenic flexure of the bowel (in this case to the right) adopts a high position while the hepatic flexure (in this case to the left) is descended and in subhepatic position

Fig 9—(Barium enema) The complete arrangement of the bowel is observed raised right flexure (splenic)

and separate ligation of the elements of the segmentary pedicles, blunt dissection of the intersegmentary layer between the anterior and apicoposterior segments of the upper lobe, aided by gentle traction of the corresponding segmentary pedicle "Block" resection of the lingula and of the anterior segment of the upper lobe Vascular ligations with silk and closure of the bronchi with interrupted stitches of silk with an Atraumatic needle, in the stump of the lower lobular bronchus, a chromic catgut No 0 suture was added Vasculobronchial anatomy corresponded exactly to that of the left lung Pulmonary re expansion with hyperpressure, double pleural drainage with apical and basal Nélaton catheters, antibiotics in the pleural cavity, closure of the thoracotomy in the usual way, drainages connected to a water-sealed system with permanent suction

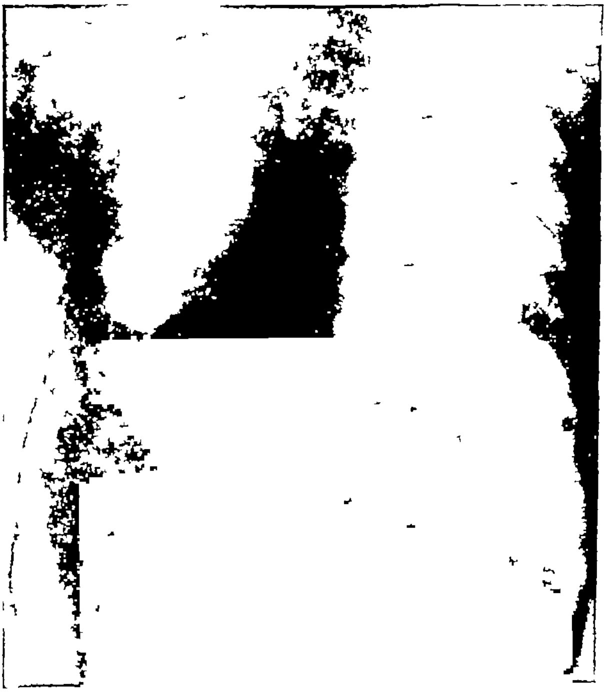


Fig 10—(Three-and one half months after the operation) Excellent pulmonary re expansion and thoracic readjustment the fifth and sixth interrupted ribs are observed rise of the right hemidiaphragm and slight pleural sequels

Postoperative Evolution—Atelectasia of the remaining parenchyma that was solved by means of bronchosuctions aseptic serohematic leakage in the operated hemithorax that was drained by repeated punctures followed by instillation of antibiotics Discharged on Oct 8, 1954 cured Conditions at this moment two or three morning sputa of mucus he maintains his gain in weight of 17 kilograms functional exploration of the lungs ventilatory reserves, 88 per cent maximum breathing capacity 48 per cent, and vital capacity, 57 per cent of theoretical figures The x-ray examination of the thorax showed an excellent thoracic readjustment with full pulmonary re expansion (Fig 10)

COMMENTARY AND CONCLUSIONS

We have presented the case of a 21-year-old man with Kartagener's syndrome, whose predominant symptomatology was a mucopurulent bronchorrhea reaching 200 c c per day, attributed to large bronchiectases of the left lung (right hemithorax) He was also in very poor general condition After 7 months of intense preoperative treatment, in which a definite relief was achieved, a right thoracotomy was performed, and was followed by a left lower lobectomy, lingulectomy, and anterior segmentectomy of the upper lobe

It is interesting to point out that the pathologic anatomy of the surgical specimen was not different from that observed in common bronchiectasis of the 'acquired type'' (Fig 11)

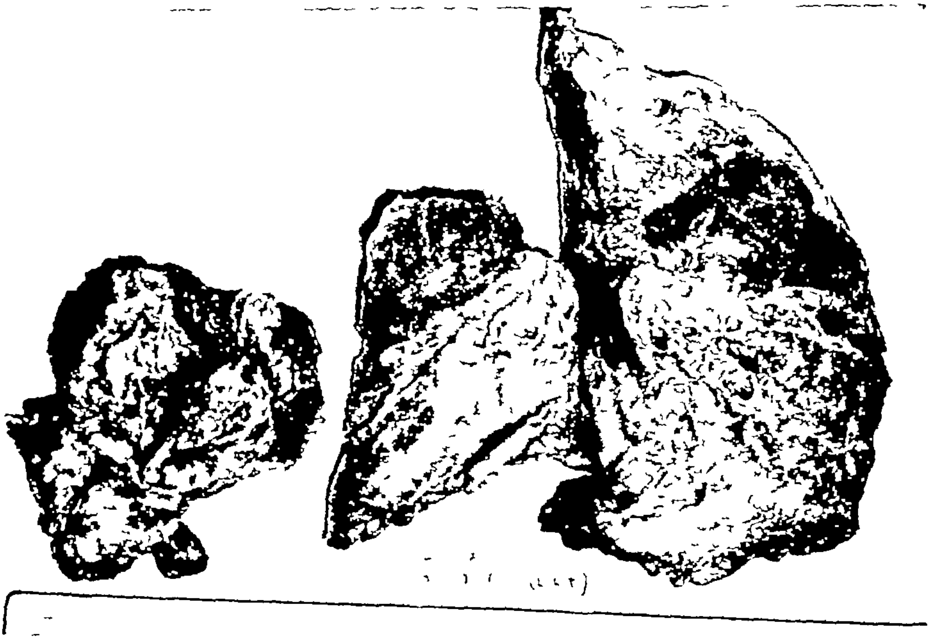


Fig 11 -

Fig 11 —(Dr Fernandez Luna.) Surgical specimens the lower left lobe (sectioned in two parts) and the lingula and anterior segment of the upper lobe (in a block) showing large bronchiectasis Microscopic findings multiple bronchiectasis with edema of the corium increase of connective tissue and slight emphysema. The microscopic findings correspond to common bronchiectasis of the acquired type

SUMMARY

Kartagener's syndrome is discussed The infrequent observation of this syndrome is emphasized and the different theories as to its pathogenesis are analyzed A review of the world medical literature is given

A case is reported which has been treated by lower left lobectomy, lingulectomy and segmentectomy of the anterior segment of the left upper lobe The patient is cured

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CONCURRENT PRIMARY LEIOMYOSARCOMA AND CARCINOMA OF THE BRONCHUS

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INTRODUCTION

PRIMARY pulmonary sarcomas are rare tumors arising from lymphoid fibrous, neurogenic, or muscular tissue components of the pulmonary architecture. Reports of primary bronchogenic leiomyosarcoma are extremely uncommon. In a review of the literature in 1946 Randall and Blades[1] were able to collect only 6 cases, and added one of their own. In 1951 Freireich and associates[2] reported one case and, more recently, Johnson and co-authors[3] recorded their experience with a primary pulmonary leiomyosarcoma treated successfully by pneumonectomy bringing the total number of reported cases to nine.

The concurrence of two tumors in the bronchus each representing a separate primary neoplasm arising from different germ layers, is even rarer. Owens and Russell[4] reported a case of concurrent leiomyosarcoma and squamous cell carcinoma in the esophagus, but we have been unable to find any report in the English literature of such tumors occurring together in the bronchus. For this reason, the following case of a primary leiomyosarcoma and of a primary undifferentiated carcinoma arising concurrently in the bronchus is reported. Of further interest is its successful treatment by pneumonectomy.

REPORT OF CASE

A 62 year old white man was admitted on Jan. 21, 1953, complaining of fatigue and frequent episodes of pneumonia during the previous fall and winter. Symptoms began during the summer when his chronic cough became more troublesome and more productive of sputum. At this time he also began to experience slight dyspnea. He was treated by his local physician with repeated injections of penicillin. Two weeks before admission he was hospitalized elsewhere for pneumonia, but, because acid fast bacilli were found in the sputum, transfer to Biggs Memorial Hospital was arranged. There had been a loss of 7 pounds during the month before admission and night sweats and fever had been noted.

Physical Examination.—Examination of the chest revealed dullness in the right upper third with increased breath sounds and many rhonchi. The left lung was clear on percussion and auscultation.

Laboratory Studies.—Fluoroscopy showed infiltration in the right upper pulmonary field, normal excursion of both diaphragms and no mediastinal shift. Roentgenography (Fig. 1) revealed a dense lesion at the right hilum extending into the pulmonary field with scattered pneumonic infiltrate throughout the upper third of the right pulmonary field.

The total white blood cell count was 12,350 per cubic millimeter with the differential being neutrophils 60 per cent, lymphocytes 16 per cent, monocytes 9 per cent, eosinophils 14

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per cent, and basophils 1 per cent Sedimentation rate was 67 mm in one hour (Westergren method) Repeated examinations of the sputum revealed no acid fast bacilli, neoplastic cells or fungi However a variety of secondary organisms were cultured from the sputum

Fig 1

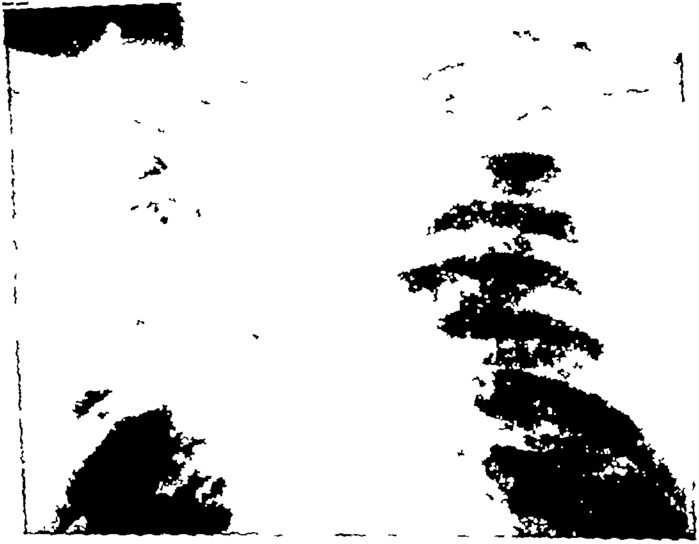

Fig 2

Fig 1—*Chest roentgenogram taken on admission to the hospital*

Fig 2—*Chest roentgenogram taken one week later The pulmonary shadows are related to an extensive lobular pneumonia principally in the upper lobe None of the shadows are related directly to the tumor of the bronchus*

Course in Hospital—On the sixth hospital day the temperature rose to 103° F and the roentgenogram (Fig 2), showed an increase in the pneumonic process in the right upper pulmonary field Penicillin and Gantrisin therapy during the next two days resulted in considerable clinical improvement Bronchoscopy on the tenth hospital day disclosed a cone shaped mass 2 cm below the carina projecting into and partially obstructing the right main bronchus It appeared to originate near the orifice of the right upper lobe bronchus, which could not be clearly visualized The trachea and left bronchial tree were considered normal A biopsy specimen was obtained without excessive bleeding On microscopic examination it was covered with pseudostratified epithelium, with connective tissue and smooth muscle between the layers of epithelium, mitotic figures were absent and no penetration of epithelium beyond the basement membrane was found No definite diagnosis of neoplasm could be made

On the twentieth and twenty first hospital days, two attacks of paroxysmal dyspnea occurred, with complete absence of breath sounds over the entire right lung During a violent episode of coughing the patient raised a piece of tissue which measured 1 by 1 by 0 5 cm Microscopic examination of this disclosed no recognizable cells since the tissue was all *necrotic*

Bronchoscopy on the twenty first hospital day again showed an irregular mass in the right main stem bronchus A considerable amount of secretion was aspirated from below the mass, and a biopsy was again done for microscopic examination The pathologic report on this third specimen was that again only necrotic tissue was present The process was suggestive of neoplasm, the nature of which could not be determined

Operation—On the twenty seventh hospital day, at exploratory thoracotomy, palpation revealed a rounded mass within the right main stem bronchus which could be displaced sufficiently to permit safe clamping of this bronchus proximally Pneumonectomy was completed without untoward incident

Postoperative Course—Apart from some difficulty in expectorating secretions and occasional episodes of slight dyspnea, the patient had an uneventful postoperative convalescence and was discharged March 27, 1953 Since then, frequent examinations in the outpatient department, the most recent on July 10, 1954, reveal that he feels well, is not dyspneic, has gained weight, and has resumed his usual work

Macroscopic Examination—Shortly beyond the resected bronchus a reddish gray mass protruded from the upper lobe bronchus into the main stem bronchus, the free projecting portion measuring 2 by 2 by 1 cm, and in this position indicating a potent ball valve mechanism Lymph nodes in the hilar region were of normal size and consistency Sections through the upper lobe showed bronchi distended with yellowish purulent material and numerous areas of lobular pneumonia No abscesses were seen and a considerable portion of the upper lobe was not involved in the pneumonic process The polypoid mass, which arose from the wall of the upper lobe bronchus (Fig 3) about 1 cm from its origin, was mushroom shaped, the stem being 1 5 by 0 8 cm. The remainder of the upper lobe bronchus appeared normal The middle and lower lobe lung tissue presented a normal appearance

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Fig 3 —This is a longitudinal section of the tumor mass Note the origin of the tumor from the bronchial wall in the lower portion of the illustration the bronchial wall of the upper lobe bronchus on either side of the tumor up to about the middle of the picture and the reddish necrotic tip of the tumor in the upper end It was from this portion of the tumor that microscopic sections showed only necrotic tissue making preoperative diagnosis impossible The upper third of the tumor lay *in the main stem bronchus and was visualized* on bronchoscopy (×2)

Fig 4 —This illustration shows the long spindle shaped cells that characterized most of the tissue as a leiomyosarcoma Mitotic figures were fairly easily found in these cells The numerous small blue dots are lymphocytes The tumor throughout showed an infiltration of leukocytes that in most areas were lymphocytes However in some areas particularly toward the necrotic tip there was a considerable *infiltration of neutrophils* Neutrophils were particularly abundant in the demarcation zone between viable and necrotic tumor tissue (×100)

Fig 5 —Another field of the tumor showing a marked anaplasia of the tumor tissue with the presence of numerous giant cells This anaplasia is seen quite often in leiomyosarcomas (×100)

Fig 6 —Illustration of a carcinoma in situ of the upper lobe bronchus Note the normal ciliated columnar epithelium in the upper third of the illustration and the alteration in the character of the epithelium below this normal area The change in the character of the epithelium occurs rather abruptly Mitotic figures were easily found in the altered epithelium In some places in areas not in the illustration there was a downgrowth of the epithelium into the submucosa and into mucous glands This carcinoma in situ was in the upper lobe bronchus and it was directly associated with the *leiomyosarcoma* No evidence of tumor metastasis was found in several hilar lymph nodes Note the similarity of the bands of normal smooth muscle, present in the upper right hand corner to the spindle shaped tumor cells in Fig 4 (×100)

Microscopic Examination—Sections through the upper lobe showed numerous areas of lobular pneumonia, organized, organizing, and in a process of resolution A tumor arising from the wall of the upper lobe bronchus showed only local invasion of the wall It was composed of long spindle shaped cells with smooth muscle cell characteristics (Fig 4) In some portions the tumor tissue was anaplastic with numerous tumor giant cells (Fig 5) being present Mitotic figures were readily found in all portions of the tumor tissue and lymphocytic infiltration was present throughout The distal end of the tumor showed considerable necrosis and neutrophilic infiltration There was no evidence of metastasis in the hilar lymph nodes Sections from the lower and middle lobes were normal apart from a few small foci of lobular pneumonia

Of particular interest was the character of the bronchial epithelium lying adjacent to but separate from the base of the leiomyosarcoma Here it was possible to demonstrate (Fig 6) a sudden change from a normal columnar ciliated epithelial lining to a multilayered ovoid to cuboidal epithelium without any ciliated columnar cells In the area of altered epithelium, mitotic figures were readily found In some areas the epithelium had grown down into the submucosa and into mucus glands No evidence was found of tumor tissue in lymph channels or in adjacent hilar lymph nodes No evidence was found of the carcinomatous change in the bronchial epithelium in the tissue section illustrated in Fig 3 The carcinoma “in situ” was found because several large blocks of tissue through the hilar portion of the lung were processed for microscopic study No evidence of carcinomatous change was found in several other sections of other bronchial branches of all lobes, both in the hilar region and out in the lung tissue

COMMENT

In the examination of numerous blocks of the excised lung an early undifferentiated carcinoma of the bronchus was found to occur independent of the sarcoma Strikingly different histologic patterns leave no doubt as to the fact that each represents a separate primary neoplasm The diagnosis of bronchial sarcoma has been successfully made by bronchoscopy on a few occasions, but it must be emphasized that necrosis and hemorrhage are characteristic of this intrabronchial group, and that a true cellular pattern is difficult to obtain The necrosis of the distal portions of the tumor can be explained by the fact that the neoplasm had outgrown its source of nourishment, as occurs not infrequently in leiomyosarcomas of the uterus It is not surprising, therefore, that bronchoscopic biopsy of tumors of this nature is of little diagnostic value From a pathologic view the cytostructural variations found in this type of tumor have always led to confusion In sections taken from different portions of the same growth many varied histologic appearances may be seen Whorling of the cells may be prominent in some regions and pseudorosette formations sometimes are present in other areas The nuclei may vary considerably in size and shape Mitotic figures may be numerous and tumor giant cells may be a dominant feature in some areas Apparently the variegated microscopic appearance of these tumors reflects anaplastic tendencies of the tumor growth

Local removal of the tumor and fulguration of the base, as advocated by Pollak and co-workers among others cannot be considered the rational form of therapy The only logical treatment is pulmonary resection as in all pulmonary malignant tumors In the management of these patients Churchill and associates[5] have emphasized the importance of clearing the bronchus by local bronchoscopic removal preoperatively This makes the lung more manageable at operation and will help to obviate uncontrollable hemorrhage from the tumor during resection.[1,2] In the absence of local and distant metastases, resection offers a better prognosis in these tumors than in bronchial carcinoma. Slow growth and late metastases are characteristics of leiomyosarcoma, the tumor often reaching large size yet remaining operable. The prognosis in the case herein reported must, however, be more guarded because of the presence of the early carcinoma.

The clinical and pathologic features illustrated by this case emphasize, too, the picture so often produced by an obstructing lesion of a bronchus, namely, repeated episodes of pneumonitis, temporarily subsiding following administration of antibiotics, but with progressive and eventually irreversible changes in the lung tissue. These changes may be patchy but extensive, sometimes progressing to formation of a frank abscess and frequently obscuring the more important etiologic factor, the obstructing tumor.

SUMMARY

A case of primary leiomyosarcoma of the bronchus, which is believed to be the tenth such report in the English literature, is presented. This case is even more unusual because of the presence of an independent concurrent early primary bronchogenic carcinoma. This is believed to be the first such combination occurring in the lung to be reported in the English literature. Currently the patient is asymptomatic and back to full-time work some twenty months following discharge.

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PNEUMONECTOMY AND PULMONARY VALVULOTOMY IN THE TREATMENT OF ACTIVE TUBERCULOSIS AND PULMONARY STENOSIS

REPORT OF A CASE

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ONE of the most stimulating advances in modern medicine during the last decade has been the development of cardiac surgery, particularly in operations on the heart valves Although the approach at first was indirect, as experience and knowledge of cardiac anomalies and physiology advanced, the attack became increasingly direct No problem illustrates this better than that of pulmonary stenosis When Blalock and Taussig[1] first created an artificial shunt to increase the pulmonary blood flow in tetralogy of Fallot, the first step was taken Within four years, both Brock[2] and Sellors[3] had successfully carried out pulmonary valvulotomy by insertion of a valvulotome through the right ventricle The simplicity, low mortality, and success of this procedure led to its widespread acceptance in the treatment of pure pulmonary valvular stenosis Recently, Dodril,[4] using an artificial by-pass of the right side of the heart, and Swan and associates,[5] employing hypothermia, have successfully opened the pulmonary artery and operated on the valve under direct vision

The extraordinary achievements of Blalock and Brock created a demand for accurate diagnosis of cardiac anomalies Both cardiac catheterization and angiocardiographic examination, as well as other studies, have become important diagnostic tools in establishing preoperatively the exact nature of cardiovascular defects Unfortunately, pulmonary stenosis is variable in type and often complicated by other anomalies that militate against complete cure by valvulotomy

Some of the variations in type introduce serious technical problems, some of the associated anomalies may vitiate seriously the results achieved by valvulotomy Forms of obstruction to blood flow from the right ventricle to the pulmonary vessels include stenosis of the valve cusps, thickening of the myocardium narrowing the outflow tract of the right ventricle, membranous

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***Assistant Physician Massachusetts General Hospital Associate in Medicine Harvard Medical School obstruction in the ventricle proximal to the valve, and atresia of the pulmonary artery. The term infundibular stenosis has been applied both to the muscular and membranous forms of obstruction. Although these variations usually exist separately, they may be found in combination. All have been treated surgically by incision and dilatation, and occasionally by excision when suitable. Stenosis of the valve itself is the most amenable to surgery, pulmonary atresia the least although Glover and associates[6] have reported initial success using dilatation in 3 cases.

The commonly associated anomalies are interatrial or interventricular septal defects, with or without dextroposition of the aorta. In general, the presence of these associated anomalies seldom constitutes a contraindication to operations for improving the pulmonary arterial flow. In many instances, although the circulation is not restored to normal by such procedures, the improvement in the patient's general condition is dramatic.

The pathological anatomy of the stenosed valve is of great importance because it has strongly influenced the surgical approach to correct it. As a rule, the cusps are fused into a thin membrane, which, by force of increased intraventricular pressure balloons out into the artery. The attack with a valvulotome is relatively simple through a ventricular incision because it can readily be passed into the taut, cup-shaped valve. At the same time, infundibular stenosis, if present, is more amenable to lysis, stretching or excision by this approach. In some cases of long standing stenosis, the valve may become thickened, vegetations may grow on it, or it may become calcified.

In pure valvular stenosis, excision under direct vision through the open artery offers a better opportunity for the establishment of a large opening, as Swan and co-workers have so readily demonstrated. Right ventricular pressures may be restored to completely normal levels by this process. The element of regurgitation introduced by the production of a large opening in the valve has not as yet been assessed for its harmful effects. Whether a large opening is actually necessary is another question. Litwak and associates have stated that embarrassment of cardiac function does not occur until the occlusion of the outlet is greater than 75 per cent. Although we do not know yet just how large an opening is necessary, cases showing persistence of right ventricular pressures considerably above normal postoperatively may, nevertheless, show gratifying clinical improvement.[8, 9] The point made by Deterling[10] that the pressure should be ascertained by direct catheterization immediately after valvulotomy seems a reasonable one, as it offers a fairly reliable check on what has been accomplished at a time when the valvulotome may be easily reinserted.

The fate of the untreated case of pulmonary stenosis is of great interest to the clinician in the planning of surgery. Greene and associates[11] in reporting their own cases and reviewing the literature found the average length of life in 62 patients to be twenty-six years. Causes of death were recorded for 59 patients: 27 died of heart failure, 10 of tuberculosis, 7 of vegetative endocarditis and 15 of various other diseases. The life span is more abbreviated in tetralogy of Fallot and in other cases in which pulmonary stenosis accompanied septal defects In most series the mortality has been preponderantly due to heart failure anoxia or bacterial endocarditis[12, 13] The incidence of tuberculosis is variable Hawes[14] cited Norris as saying that one-third of 449 patients with pulmonary stenosis who were examined at autopsy also had tuberculosis In most of the recent series however it is far less common than this particularly in those reported by surgeons Sellors'[3] case is a notable exception. White[15] in discussing the combination of tuberculosis and valvular heart disease remarked that the pulmonary circulation is engorged in mitral stenosis in which tuberculosis is quite rare but may be deficient in pulmonary stenosis in which tuberculosis is quite common

The relation of diabetes and tuberculosis has been reported by a number of investigators Reaud[16] found an incidence of 0 98 per cent in 3 850 tuberculous patients Ferrara[17] found that 2 1 per cent of 3,178 tuberculous patients had diabetes Both authors indicated that the pulmonary disease was likely to be more advanced among diabetic than nondiabetic patients and therefore the prognosis was more grave The diabetic patients however, did as well as other patients with similar degrees of infection once therapy had been instituted

We present the following case in which the coexistence of advanced pulmonary tuberculosis and pulmonary stenosis posed a difficult problem in judgment and dictated an unusual surgical approach

CASE REPORT

L. O (M G.H. S29049), a 30 year old man was admitted to the hospital When he was 6 years of age a systolic murmur had been noted but it had not interfered with normal development and he had been able to participate in all sports throughout the school years When he was 23 years of age he started to lose weight and did not feel well Examination disclosed the presence of diabetes which required 40 units of protamine zinc insulin daily Despite a diet and insulin he continued to lose weight and developed a productive cough A roentgenogram of the chest (Fig 1) disclosed multiple densities in the left lung and a cavity in the left upper lobe The right lung was clear The sputum contained tubercle bacilli and the patient was sent to a sanitarium On bed rest and streptomycin the right lung remained clear but a sizable cavity persisted in the left hemithorax and the sputum remained positive The patient became increasingly dyspneic and cyanotic and there was clubbing of the fingers At this time a diagnosis of pulmonary stenosis was made Resection of the left lung was considered but rejected as being too hazardous Therefore a cavernostomy (Monaldi procedure) was carried out through the second interspace anteriorly A year later although there was persistent drainage from the cavity requiring a tube the patient returned to his home The cavity was reduced in size but the sputum and drainage remained positive The patient gained some weight but was confined to a bed and chair existence After two years he was no better and the question of surgery was again raised

When admitted to our hospital the patient was thin cyanotic and dyspneic on the slightest exertion The temperature pulse and respirations were normal at rest A harsh systolic murmur was heard in the pulmonic area The left side of the chest was dull to percussion and purulent fluid was still draining through a small anterior catheter The fluid was positive for tuberculosis on smear The sputum was small in amount and positive on culture The white cell count was 11 700 the hemoglobin 19 3 Gm per 100 c c and the hematocrit 54 per cent Other laboratory studies were negative The diabetes was well controlled on 40 units of insulin

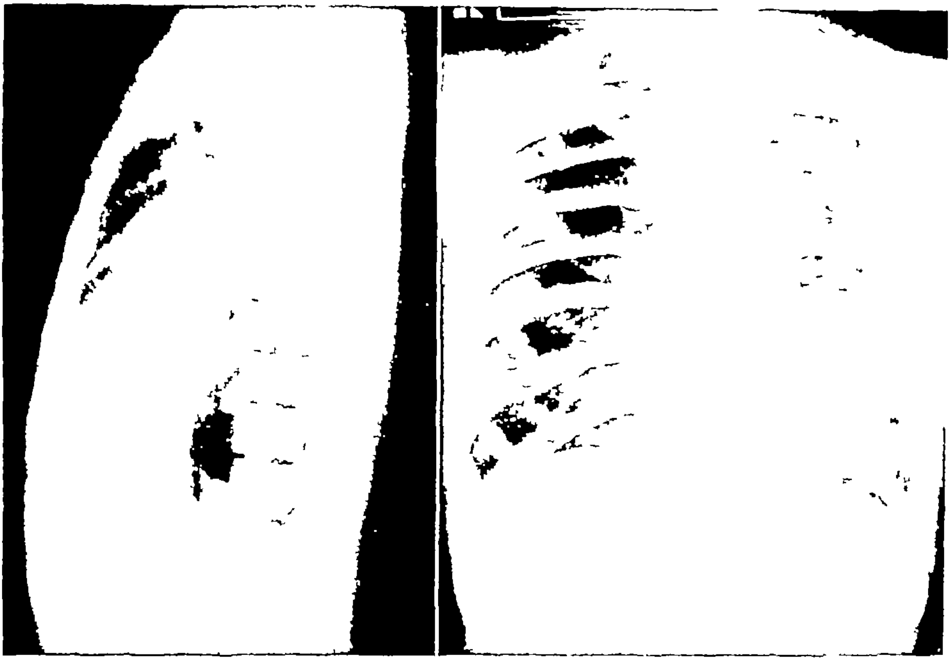

Fig. 1.—Roentgenograms of the chest when pulmonary tuberculosis was first diagnosed. There is a diffuse infiltration of the left lung and a cavity in the upper lobe. The cardiac contour is not remarkable.

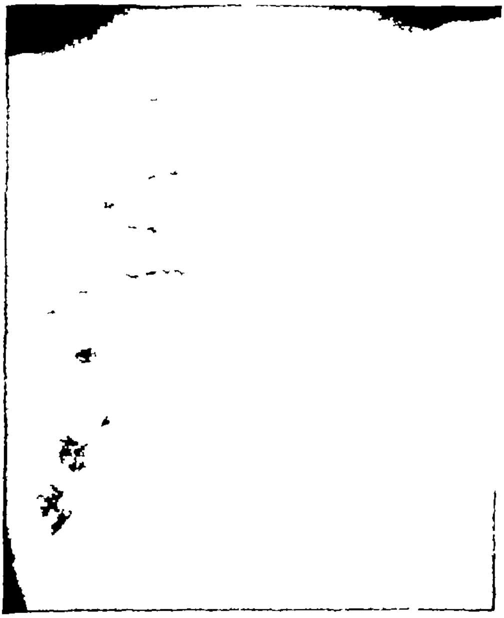

Fig. 2.—Chest roentgenogram on admission to the Massachusetts General Hospital six years after the onset of the disease. A tube can be seen draining an empyema cavity anteriorly.

Roentgenograms of the chest (Fig 2) showed a normal right lung and complete opacification of the left side of the chest with the exception of a small cavity in the upper anterior portion The heart shadow was completely obscured by the opacity Review of the x ray films led us to believe that the cavity that had been drained was an empyema cavity with a bronchopleural fistula rather than an intrapulmonary cavity because of the thickened pleura around it and the absence of overlying lung markings When fluid was introduced into the cavity it was coughed up promptly Further evidence in favor of our opinion was the knowledge that, after cavernostomy, the drainage tract usually becomes free of tubercle bacilli but after drainage of a tuberculous empyema it usually does not

An electrocardiogram was characteristic of right ventricular hypertrophy Cardiac catheterization was carried out and the results are summarized in Table I and Fig 3 The catheter passed readily through an atrial septal defect into the left atrium The catheter also passed easily into the right ventricle but could not be advanced into the pulmonary artery

TABLE I. A COMPARISON OF THE CARDIAC CATHETERIZATION DATA OF PATIENT L O COLLECTED PRE AND POSTOPERATIVELY WITH THE VALUES OBTAINED IN NORMAL SUBJECTS

	M V L./MIN	O CONS (C C/MIN)	O CAP (VOL %)	ART O SAT (%)	A V DIFF (VOL %)	PULM ART FLOW L./MIN/M²	SYSTEMIC FLOW L./MIN/M²	R→L SHUNT L./MIN/M²	P A. PRESSURE MM HG	R V PRESSURE MM HG	P A. PRESSURE MM HG
Normal	7.5	200	20.0	95	4.0	3.2	3.2	0	30/10	30/0	5
Preoperative Oct 30 1953	10.6	299	25.0	78	10.8	1.7	3.1	1.4	-	200/0	5
Postoperative March 8 1954	5.9	166	14.8	95	4.1	2.4	2.4	0	20/4	83/0	3

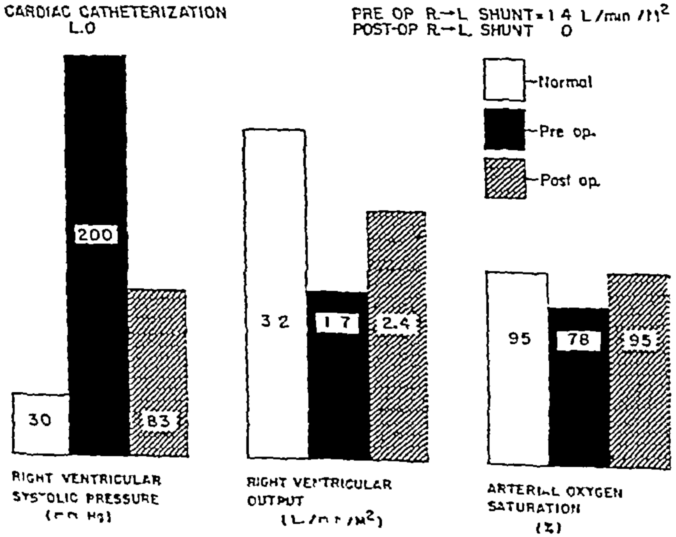

Fig 3—Schematic representation of right ventricular pressures output and arterial oxygen saturation taken pre and postoperatively and compared with the normal

In the absence of data concerning the pressure in the pulmonary artery it was impossible to conclude whether the marked hypertension (200/0) of the right ventricle was due to pulmonary stenosis or to pulmonary vascular disease and pulmonary fibrosis

Angiocardiographic examination using Diodrast was performed to clarify the diagnosis. This confirmed the presence of an atrial septal defect. No evidence of infundibular stenosis was seen. Valvular stenosis was not demonstrated but could not be excluded. A large main pulmonary artery was visualized. Because of the large atrial septal defect, determinations of circulation time were considered of little value to ascertain the presence of stenosis.

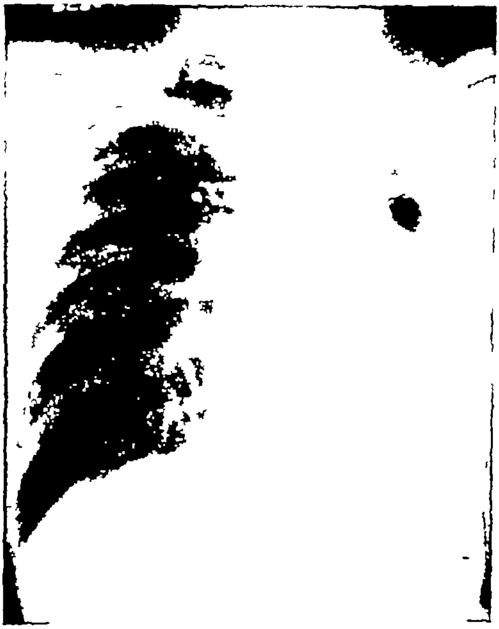

Fig. 4.—Chest roentgenogram taken four months after pulmonary valvulotomy, pneumonectomy, and pleurectomy. A residual intrathoracic cavity is still present.

After some debate, it was decided to explore the heart through the left side of the chest, and if the presumptive diagnosis of pulmonary stenosis was confirmed, to perform a valvulotomy through the artery and then an extrapleural pneumonectomy as described by Sarot.[18] On Nov. 9, 1953, a left posterolateral thoracotomy incision was made and the fifth rib excised. The extrapleural plane was entered and the left pleural sac and left lung were mobilized with some difficulty. Dissection of the lung and pleural sac from the mediastinum disclosed an enlarged soft pulmonary artery. There was a well transmitted systolic thrill consistent with the diagnosis of pulmonary stenosis. Accordingly, the pericardium was opened and a segment of the left pulmonary artery isolated between two traction ligatures. A uterine probe was then inserted through a small incision in the artery, and the presence of pulmonary stenosis was confirmed. The valve orifice was easily identified. It was incised using a Brock valvulotome passed in a retrograde fashion through the arteriotomy, followed by dilatation using a common duct stone grasping forceps. The left pulmonary artery was then ligated and divided and the left pleuropneumonectomy completed. The patient's cardiovascular state remained good throughout, but toward the conclusion of the operation pin point oozing was apparent within the entire chest cavity and incision. The chest was closed rapidly after insertion of a catheter for drainage.

The early postoperative course was stormy. Constant oozing from the incision and the chest tube persisted despite six transfusions and did not subside until fresh blood was given A transitory deficiency in platelets was considered to be the most likely cause of the bleeding Meanwhile the diabetes was controlled with some difficulty The pathologic study of the excised lung and pleura demonstrated extensive caseous tuberculosis and tuberculous empyema

The patient left the hospital two weeks after operation At this time the incision was well healed The site of the previous drainage had been closed. The cyanosis and dyspnea were greatly improved

The patient returned for evaluation four months after the operation At this time he was not cyanotic and the dyspnea was considerably improved The sputum was negative for acid fast organisms Cardiac catheterization was performed The results are included in Table I and Fig 3 Of special interest was the marked fall in the systolic pressure in the right ventricle from 200 to 83 mm of mercury despite a rise in right ventricular output The pressure gradient persisting between the right ventricle and the pulmonary artery revealed some degree of pulmonary stenosis

Arterial oxygen saturation before operation of 78 per cent had risen to a normal value of 95 per cent, evidence that a significant right to left shunt through the atrial septal defect was no longer functioning A chest roentgenogram demonstrated the presence of an interthoracic air and fluid filled cavity which continued to drain purulent material positive for tubercle bacilli (Fig 4)

The patient was last heard from eighteen months after operation The clinical improvement was well maintained He had gained weight, and the sputum remained negative A residual area of infection in the left thoracic cavity had been treated surgically by Dr Colin A Ross of Edmonton, Alberta

SUMMARY

A case of pulmonary stenosis, interatrial septal defect, pulmonary tuberculosis, and diabetes has been presented, to illustrate the feasibility of a combined transarterial valvulotomy and extirpative pulmonary surgery A satisfactory clinical result was obtained

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ARTERIALIZATION OF THE CORONARY SINUS FOR THE REVASCULARIZATION OF THE HEART IN CORONARY ARTERY DISEASE. MORTALITY STUDY FOLLOWING CIRCUMFLEX CORONARY ARTERY LIGATION

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IN RECENT years, stimulated by the work of Roberts[1] and Beck[2, 3] in the revascularization of the heart for occlusive coronary artery disease, we have been performing aorticocoronary sinus anastomoses. Reports from this clinic have indicated that it is anatomically feasible for aortic blood delivered to the coronary sinus to reach the myocardial capillary bed in retrograde fashion.[5-8]

During the course of our original experiments on the physiology of the sinus arterialized heart of four to eight weeks' duration, we noted a definite protection afforded to it against ventricular fibrillation following acute occlusion of the left circumflex coronary artery. However, our subsequent experiments on sinus arterialized hearts of six months' duration revealed a significant loss of this protection.

Hahn and Beck[4] have previously noted this protection which consisted of a reduction in both the mortality and size of infarct following major coronary artery ligation. Eckstein and associates[9, 10] have also noted a definite protection afforded to the acutely arterialized heart following circumflex artery ligation.

The technique for arterialization of the coronary sinus which we used was originally conceived by Pratt[13] and Roberts[1] and was developed and described by Beck and his associates.[2, 3] It consists of a two-stage operation. At the first stage through a left sided thoracic incision, a free segment of external jugular vein is used to anastomose the aorta to the coronary sinus. Three to six weeks later, through a right-sided approach, the coronary sinus is partially ligated over a probe to 2 to 3 mm. Subsequently, the animals are used for the physiologic experiments.

In an effort to study the pathologic effects on the myocardial venous bed of elevating the pressure within the coronary sinus by arterialization, all animals were sacrificed after the physiologic data were obtained.

For the purposes of this comparative mortality report, those animals living for 4 hours following the ligation of the circumflex coronary artery were classified as survivals.

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RESULTS

1. *Group A (Normal Dogs)*.—The results in this group may be seen in Table I. In the first 9 dogs, following circumflex coronary artery ligation, ventricular fibrillation ensued within 3 to 30 minutes, with an average time of 13.7 minutes. One dog died after 36 hours. The retrograde blood flow from the distal segment of the ligated and transected circumflex coronary artery ranged from 0.4 to 5.0 c.c. per minute, with an average of 1.7 c.c. per minute. The mean coronary sinus pressure ranged from 2 to 12 cm. of water with an average of 6.1 cm. of water. The coronary sinus pressure of Dog 10 was 4 cm. of water, which was within the range of the average normal, and could not be related to the 36-hour survival time.

TABLE I. MORTALITY IN NORMAL DOGS FOLLOWING LIGATION OF THE CIRCUMFLEX BRANCH OF THE LEFT CORONARY ARTERY

DOG	TIME BETWEEN LIGATION AND DEATH	CAUSE OF DEATH	CORONARY SINUS PRESSURE (CM. H_2O)	RETROGRADE CIRCUMFLEX ARTERY BLOOD FLOW (C.C./MIN.)
1	30 min.	Vent. Fib.	12	2.2
2	18 min.	Vent. Fib.	2	4.4
3	20 min.	Vent. Fib.	5	0.4
4	3 min.	Vent. Fib.	8.6	0.4
5	4 min.	Vent. Fib.	8.4	0.5
6	15 min.	Vent. Fib.	4.6	0.6
7	16 min.	Vent. Fib.	4.0	1.1
8	5 min.	Vent. Fib.	7	1.0
9	12 min.	Vent. Fib.	5	5.0
10	36 hr.	[a]	4	1.4
AVERAGE	13.7 min.		6.1	1.7

Vent. Fib. = Ventricular fibrillation.

Inasmuch as we have arbitrarily chosen 4 hours as the statistical basis for our mortality study, and one normal dog lived past this time interval, the mortality rate in our normal series of animals was 90 per cent. However, since at post-mortem examination, the tenth animal obviously had died a cardiac death, without complicating factors, our actual mortality in circumflex arterial ligation was 100 per cent.

2. *Group B (Dogs With Previous Miscellaneous Cardiac Operations)*.—The results in this group are tabulated in Table II.

A. In those dogs in which the circumflex branch of the left coronary artery was ligated, three died of ventricular fibrillation within 14 to 20 minutes, one died of cardiac arrest in 17 minutes, one survived for 48 hours, and one survived for 40 days. Retrograde circumflex arterial blood flow ranged from 0.5 to 6.0 c.c. per minute with an average of 1.9 c.c. per minute. Coronary sinus pressure ranged from 4.0 to 12 cm. of water, and averaged 6.7 cm. of water. The mortality rate in this series of animals was 66 per cent.

B. In the group of dogs in which the left anterior descending artery was ligated at its origin, three died of ventricular fibrillation in 1 to 23 minutes. Two animals lived until they were sacrificed at 40 days. The retrograde blood flow from the distal cut end of the artery ranged from 1.5 to 11.0 c.c.

per minute, with an average of 5.1 cc per minute The coronary sinus pressure ranged from 4 to 10 cm of water, with an average of 6.6 cm of water Thus, in this group of animals, the mortality rate was 60 per cent

In both groups of animals, there was no demonstrable correlation between coronary sinus pressure and survival following coronary artery ligation Of the animals in which the left anterior descending artery was ligated, two survived In both, an accessory left anterior descending artery arose from the circumflex artery (Fig 1) and coursed downward over the left ventricle parallel to the left anterior descending artery In both animals the retrograde blood flow from the distal cut end of the anterior descending artery was significantly greater than the normal average

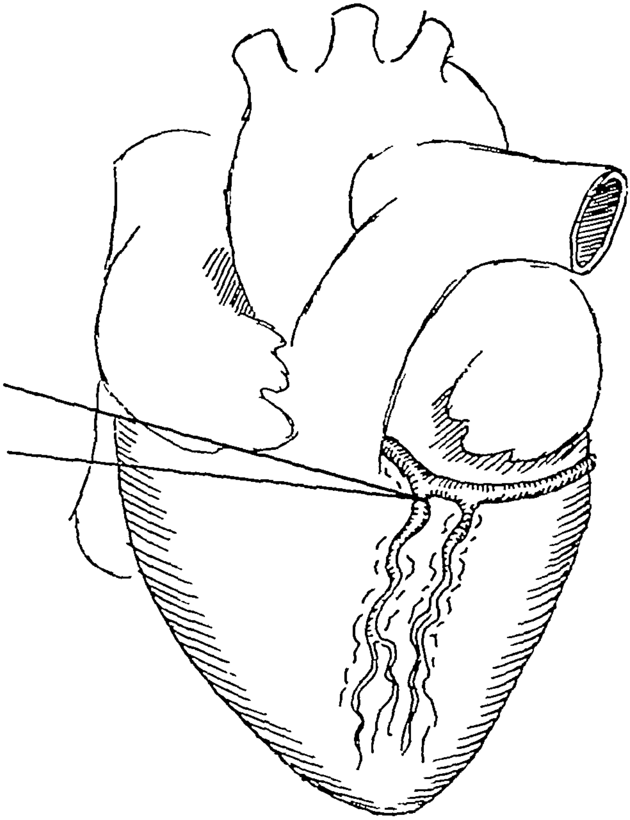

Fig 1—An accessory left anterior descending artery is seen to arise from the circumflex coronary artery 0.5 cm distal to its origin. The accessory vessel courses downward over the left ventricle parallel to the left anterior descending artery and provides for an abundant amount of intercoronary arterial anastomotic flow

3 *Group C (Dogs With Coronary Sinus Arterialized for 4 to 8 Weeks)*—The results in this group are tabulated in Table III In this group, following circumflex coronary artery ligation, two dogs have survived for a prolonged period of time and six dogs survived from 6 to 96 hours with an average time of 28 hours This provides a mortality rate of 20 per cent It

TABLE II. MORTALITY IN DOGS HAVING HAD PREVIOUS MISCELLANEOUS CARDIAC SURGERY FOLLOWING MAJOR CORONARY ARTERY LIGATION

DOG	TIME ELAPSED FROM LIGATION TO DEATH	CAUSE OF DEATH	CORONARY SINUS PRESSURE (CM. H_2O)	RETROGRADE BLOOD FLOW (C.C./MIN.)	REMARKS
Ligation of the Circumflex Branch of the Left Coronary Artery					
1	40 days	?	5.4	1.1	Thrombosed Beck, coronary ligation 3 weeks after surgery
2	20 min.	Vent. Fib.	6.0	1.2	Thrombosed Beck, coronary ligation 3 weeks after surgery
3	17 min.	Cardiac arrest	23	1.2	Previous atrioseptal defect created under hypothermia in severe congestive failure
4	20 min.	Vent. Fib.	12	6.0	Thrombosed Beck, coronary ligation 5 weeks after surgery
5	14 min.	Vent. Fib.	6.4	0.5	Open and close of right auricle under hypothermia
6	48 hr.	?	4.0	1.4	Thrombosed Beck
Ligation of the Anterior Descending Ramus of the Left Coronary Artery					
1	10 min.	Vent. Fib.	4	1.8	Right auricle opened under hypothermia
2	23 min.	Vent. Fib.	7	1.5	Atrioseptal defect created and closed under hypothermia
3	1 min.	Vent. Fib.	5	No sample	Atrioseptal defect created and closed under hypothermia
4	40 days	Sacrificed	10	6.2	Atrioseptal defect created and closed under hypothermia, accessory L.A.D. from circumflex coronary artery
5	40 days	Sacrificed	7.2	11.0	Atrioseptal defect created and closed under hypothermia, accessory L.A.D. from circumflex coronary artery

Vent. Fib. = Ventricular fibrillation
L.A.D. = Left anterior descending artery

should be noted that the two animals surviving the procedure had no pleural adhesions and therefore no pulmonary air leaks. Five of the six animals, dying after 6 hours, died of a tension pneumothorax; the sixth died of

TABLE III. MORTALITY IN DOGS WITH CORONARY SINUS ARTERIALIZATION OF ONE TO TWO MONTHS DURATION FOLLOWING CIRCUMFLEX CORONARY ARTERY LIGATION

DOG	TIME BETWEEN ARTERIAL LIGATION AND DEATH	CAUSE OF DEATH	CORONARY SINUS PRESSURE (CM. H_2O)	RETROGRADE BLOOD FLOW (C.C./MIN.)
1	24 hr.	Tension pneumothorax	45	9.6
2	10 hr.	Tension pneumothorax	80	9.0
	24 hr.	Hemorrhage	60	11.0
4	1 hr. (3 min. after the graft clamped)	Cardiac arrest	36	12.0
5	2 hr. (5 min. after the graft clamped)	Ventricular fibrillation	60	12.0
6	96 hr.	Pneumothorax and empyema	71	10.0
7	Survived	No pleural adhesions present	64	18.0
8	Survived	No pleural adhesions present	59	10.0
9	6 hr.	Tension pneumothorax	68	14.0
10	12 hr.	Tension pneumothorax	70	16.0

hemorrhage from the transected coronary artery Two animals died within 6 hours In both, the heart beat well for 1 to 2 hours following circumflex coronary artery ligation In both the vein graft was occluded, for the collection of data after which both expired of ventricular fibrillation It was impressive to note the rapid onset of ventricular fibrillation following occlusion of the graft in hearts which had been beating forcefully for long periods of time prior to the occlusion of the graft

Retrograde blood flow ranged from 9 0 to 18 0 c c per minute with an average of 12 2 c c per minute Mean coronary sinus pressure ranged from 36 to 80 cm of water with an average of 61 cm of water It is interesting to note that there was apparently no relationship between the mortality rate and either the mean coronary sinus pressure or the retrograde circumflex arterial blood flow

4 *Group D (Dogs With Coronary Sinus Arterialized for Six Months)*.—The results of this group are tabulated in Table IV In this group following circumflex coronary artery ligation only two dogs survived for 4 hours before sacrifice Four dogs died of ventricular fibrillation within 1 hour of arterial ligation with an average time of 94 minutes This provides a mortality rate of 66 per cent Retrograde circumflex arterial blood flow ranged from 3 to 18 c c with an average of 8 3 c c per minute Mean coronary sinus pressure ranged from 85 to 100 cm of water with an average of 90 cm It is again of interest to note that there was no obvious relationship between the survival rate and either the mean coronary sinus pressure or the retrograde circumflex arterial blood flow

TABLE IV MORTALITY IN DOGS WITH CORONARY SINUS ARTERIALIZATION OF SIX MONTHS DURATION FOLLOWING CIRCUMFLEX CORONARY ARTERY LIGATION

DOG	TIME BETWEEN ARTERIAL LIGATION AND DEATH (MIN)	CAUSE OF DEATH	CORONARY SINUS PRESSURE (CM H O)	RETROGRADE BLOOD FLOW (C C/MIN)
1	30	Vent Fib	85	18
2	240	Sacrificed	90	9
3	240	Sacrificed	90	4
4	20	Vent Fib	85	7 5
5	12	Vent Fib	90	3
6	20	Vent Fib	100	8
AVERAGE	94		90	8 3

Vent Fib = Ventricular fibrillation

DISCUSSION

In these experiments on the normal dogs and those in which the coronary sinus had been arterialized for 4 to 8 weeks we were originally impressed by an apparent protection afforded the heart by coronary sinus arterialization against the onset of ventricular fibrillation following major coronary artery ligation This impression was quickly dispelled by our subsequent experiments on animals in which the coronary sinus had been arterialized for 6 months In the group of normal animals and in those having had previous miscellaneous cardiac operations we found it imperative to expedite the collection of data before ventricular fibrillation ensued After the coronary sinus had been arterialized for 4 to 8 weeks however, the heart continued to beat in vigorous uninterrupted fashion following circumflex coronary artery ligation We soon learned that in these animals we could proceed more deliberately in securing our blood samples, providing the graft was functioning Once the graft was occluded, data had to be obtained with dispatch, lest the heart fibrillate In two dogs in which the heart beat well for 1 and 2 hours, respectively, following ligation of the circumflex artery, ventricular fibrillation ensued within 5 minutes of the occlusion of the graft This observation could not be substantiated in our subsequent experiments on animals in which the coronary sinus had been arterialized for 6 months In this group though we had more time to collect data than in the normal group, we were singularly unimpressed by the afforded protection to the heart against ventricular fibrillation by the presence of the graft These findings have been previously described by others Hahn and Beck[4] ligated the descending ramus of the left coronary artery in normal and in sinus arterialized animals with essentially similar results These investigators noted a 70 per cent mortality following left anterior descending ligation in the normal dogs and the myocardial infarcts were extensive in those surviving ligation In sinus arterialized dogs, the mortality fell to 11 per cent In these dogs a gross infarct was absent in more than one-half of the specimens, and in the remaining ones the myocardial destruction was limited to small areas In ten dogs which had had previous unsuccessful sinus arterialization with subsequent thrombosis of the graft, ligation of the anterior descending artery again resulted in a 70 per cent mortality

Eckstein and co-workers,[9, 10] in experiments on acutely prepared sinus arterialized animals demonstrated an immediate protection to the heart against ventricular fibrillation following circumflex coronary artery ligation In those experiments the animal was deemed a survival if it lived for more than 60 minutes following circumflex coronary artery ligation In a group of normal control animals seven died of ventricular fibrillation within an average time of 8 9 minutes Three lived more than 60 minutes (one developed ventricular fibrillation in 67 minutes) In a group of acutely prepared sinus arterialized animals, none died within the prescribed 60 minutes One died in 62 minutes of cardiac arrest, and one died of ventricular fibrillation in 3 hours

Eckstein's experiments suggest a protection to the heart against ventricular fibrillation in acutely prepared sinus arterialized animals This suggests an immediate protection explained by the retrograde perfusion of the myocardial capillary bed without the development of increased intercoronary arterial anastomotic flow In our previous work[11] in addition to the retrograde perfusion of the myocardial capillary bed with arterialized blood introduced into the coronary sinus we were able to demonstrate a definite increase in the intercoronary anastomotic flow

Our mortality rates in the first portion of these experiments were essentially similar to those reported by Hahn and Beck Ligation of the circumflex coronary artery resulted in a 90 per cent mortality rate in normal animals The average time of onset of ventricular fibrillation was 13 7 minutes following ligation of the artery The length of elapsed time prior to the onset of ventricular fibrillation was not apparently related to either the coronary sinus pressure or the retrograde blood flow from the distal end of the transected circumflex coronary artery In those dogs which had had previous miscellaneous cardiac surgery circumflex coronary artery ligation was associated with a 66 per cent mortality within 20 minutes due to ventricular fibrillation When the left anterior descending artery was ligated in those animals having had previous miscellaneous cardiac surgery the mortality rate was 60 per cent Of the two animals surviving anterior descending ligation both had accessory anterior descending vessels arising from the circumflex branch of the left coronary artery The accessory vessel arose 0 5 cm to the left of the anterior descending artery and coursed over the left ventricle to the apex parallel to it (Fig 1) In both animals coronary sinus pressure was slightly higher than average but within normal limits However in both animals the retrograde arterial flow from the distal cut end of the vessel was significantly increased above the normal average (see Table II) This increased arterial backflow is probably a measure of a more abundant intercoronary arterial anastomotic flow which in turn explains the survival of these animals following anterior descending coronary ligation.

The mortality rate following left anterior descending coronary artery ligation in our small series was 60 per cent The mortality rate reported by Hahn and Beck in their series of animals was 70 per cent It is interesting to speculate whether the surviving animals in their series also had such an anomalous accessory left anterior descending artery

The mortality rate in the animals in which the coronary sinus had been arterialized for 4 to 8 weeks was 20 per cent Two of these animals in which the pleural cavity was free from pleural adhesions survived circumflex coronary artery ligation for 3 months until sacrificed All of the six animals in which lung leaks were produced died of tension pneumothorax empyema or hemorrhage Two animals died within 2 hours one of ventricular fibrillation and the other of cardiac arrest It is interesting to note that in both the heart beat regularly and forcefully until the vein graft was clamped In both animals ventricular fibrillation ensued shortly after the vein graft was occluded

In those animals in which the coronary sinus had been arterialized for 6 months the mortality rate following circumflex coronary arterial ligation was 66 per cent The average time elapsing between arterial ligation and death was 94 minutes It should be realized that in the normal group of animals although the mortality rate following ligation of the circumflex coronary artery was 90 per cent the figure fell to 66 per cent in those animals in which previous miscellaneous cardiac operations had been performed Thus in the group of animals in which the coronary sinus had been arterialized for 6 months the mortality rate following circumflex coronary arterial ligation was unchanged from that subsequent to circumflex ligation in a group of normal animals having previously had miscellaneous cardiac procedures Moreover, although we had noticed a protection afforded to the heart after the coronary sinus had been arterialized for 1 to 2 months, we were unable to repeat and confirm these observations in subsequent experiments on the 6-month-group of animals In this latter group, we did note that a longer period of time elapsed between the ligation of the circumflex artery and ventricular fibrillation We were unable to demonstrate, however, that the occlusion or the opening of the vein graft had any effect upon the speed of onset of ventricular fibrillation In the two animals which survived arterial ligation, the vein graft had been clamped for the last 2 hours prior to sacrifice It was our impression and general conception that arterialization of the coronary sinus originally provided for a retrograde perfusion of the myocardial bed, in addition to stimulating the intercoronary arterial anastomotic flow This was demonstrated in our original experiments on the group of animals in which the coronary sinus had been arterialized for 1 to 2 months In the group of animals in which the coronary sinus was arterialized for 6 months,[12] although we were able to confirm a fivefold increase in the intercoronary arterial anastomotic flow we were unable to demonstrate the presence of any retroperfusion of the myocardial capillary bed This led us to believe that although the graft stimulated an increase in the intercoronary anastomoses, something happened between the second and sixth month which prevented the retroperfusion of the myocardium We were impressed by the obvious ineffectiveness of the opening or the clamping of the vein graft upon the protection of the heart against ventricular fibrillation We have examined a group of these hearts pathologically, and have noted a striking intimal proliferation with thrombosis and occlusion of the major tributaries of the coronary sinus The occlusion of these major venous tributaries is adequate explanation for the loss of retroperfusion of the myocardial capillary bed A complete exposition of these pathologic findings will be presented in a subsequent report

Thus in our experiments on major coronary artery ligation in normal animals in those which have had previous miscellaneous cardiac surgery and those in which the coronary sinus had been arterialized we were unable to demonstrate any significant prolonged protection against ventricular fibrillation afforded to the heart by arterialization of the coronary sinus

SUMMARY AND CONCLUSIONS

1 The circumflex coronary artery was ligated in normal dogs, with a 90 per cent six-hour mortality rate and an eventual 100 per cent mortality rate

2 Ligation of the circumflex coronary artery in dogs which have had previous miscellaneous cardiac surgery resulted in a 66 per cent mortality rate The 33 per cent survival rate was not apparently related to either coronary sinus pressure or the amount of retrograde blood flow from the distal cut end of the ligated coronary artery

3 Ligation of the left anterior descending artery in similar dogs resulted in a 60 per cent mortality rate Two survivors demonstrated an accessory

left anterior descending artery arising from the circumflex coronary artery This accessory vessel probably accounted for an increase in the intercoronary arterial anastomotic flow which was adequate to protect the heart against ventricular fibrillation

4 Ligation of the circumflex branch of the left coronary artery in animals in which the coronary sinus was arterialized for 1 to 2 months resulted in a 20 per cent mortality It is of interest that in the two dogs that died the heart beat well for 1 and 2 hours, respectively following circumflex artery ligation Ventricular fibrillation ensued in both animals within 5 minutes of occlusion of the graft We were originally impressed by the protection afforded by the anastomosis of the aorta to the coronary sinus

5 Ligation of the circumflex branch of the left coronary artery in animals in which the coronary sinus had been arterialized for 6 months produced a 66 per cent mortality In this group we were unable to demonstrate any significant protection against ventricular fibrillation afforded by arterialization of the coronary sinus

6 This loss of protection was accompanied by a loss of retroperfusion of the myocardium which was explained by a marked intimal proliferation and thrombosis within the major venous tributaries of the coronary sinus

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A TECHNIQUE FOR THE EXPERIMENTAL CREATION OF AORTICOPULMONARY FISTULA

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CONGENITAL aorticopulmonary fistula, although physiologically and clinically related to patent ductus arteriosus, is on the whole a much rarer condition. Gasul, Fell, and Casas[1] in reporting a case of this anomaly in 1951, indicated that only twenty-four cases had been previously recorded in the literature. Gibson[2] and Spencer[3] have discussed the clinical syndrome associated with this lesion. Other recorded interest[4] in this problem has concerned the development of methods for surgical closure of this abnormal shunt.

From a clinical and physiological viewpoint, the term aorticopulmonary fistula is probably most suitable. Other descriptive terms that have been applied are aortic-pulmonary window and aortic septal defect. Because this anomaly produces alterations in circulatory dynamics which parallel those of patent ductus arteriosus (although usually of a more severe degree), and is usually diagnosed clinically as patent ductus arteriosus, it would seem more purposeful to retain the term aorticopulmonary fistula.

The embryogenesis of these fistulas is probably related to arrested development of the aortic septum between the fifth and eighth weeks of intra-uterine life. Normally the truncus arteriosus undergoes separation into separate channels by the growth of the aortic septum. The failure of growth or fusion of the anlagen of the aortic septum may result in a partial persistence of the truncus arteriosus into the postnatal period, with a resulting aortic septal defect. Depending on the degree of arrested growth, windowlike communications between the aorta and pulmonary artery result, varying from small to large openings located from a few millimeters to several centimeters distal to the valve cusps. Typically the defect is about 1.5 cm. in diameter and without significant length. Surgical attempts at closure of these fistulous communications have been fraught with the dangers of uncontrollable hemorrhage due to their proximity to the valve cusps of both the pulmonary artery and aorta. Although a few successful cases have been reported,[4-7] most cases have been left untreated.

Scott and Sabiston,[8] in 1953, reported on an experimental method for the creation and closure of aorticopulmonary fistula. This technique involved

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the dissection of the base of the aorta and pulmonary artery and direct suture anastomosis of these two vessels after applying Potts ductus clamps. In this way a fistula was created which lay about 1 cm from the aortic valve and even less from the pulmonary cusps. In their experience, fistulas over 6 mm in diameter did not permit a long-term survival, death resulting from pulmonary edema in four to ten days. Closure of these fistulas was successfully accomplished in five of twelve long-term survivors, by dissection of the fistula, reapplication of Potts clamps with division, and oversewing of the previous anastomosis.

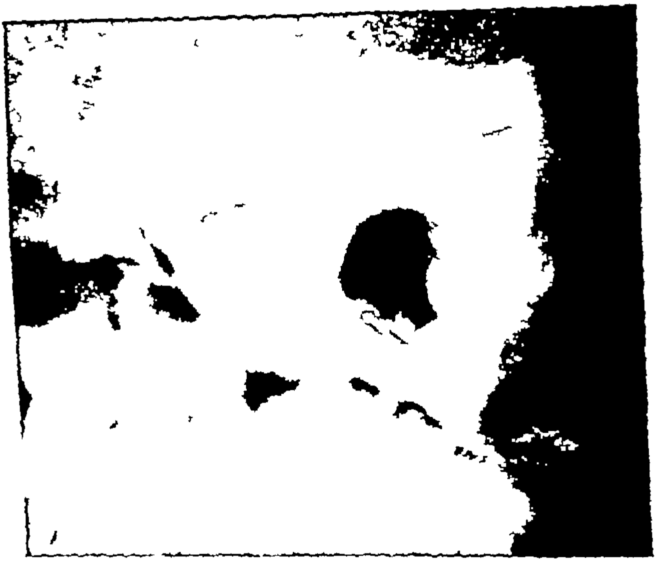

Fig 1.—Photograph of a congenital aorticopulmonary septal defect viewed through the opened aorta. The patient was an 11-year-old girl who suffered from repeated episodes of pneumonia and had suffered five years previously an attack of bacterial endocarditis which was controlled with antibiotics. This patient expired at surgery due to a tear incurred (indicated by the probe) as an attempt was made to dissect the inferior margin of the fistula. Note similarity with experimental defects.

It is our opinion that the technique of Scott and Sabiston is sound. However, a review of the pathologic anatomy of this defect reveals that in some aspects a fistula created by the suture technique may not be comparable to many cases of aorticopulmonary window seen clinically. When the levels of the cusps of the pulmonary artery and the aorta are observed in the transverse plane it can be seen that the aortic cusps lie approximately 0.5 to 1 cm below those of the pulmonary artery. However aortic septal defects seen clinically are frequently located in such fashion as to be equidistant from both sets of cusps and may in fact include a portion of the cusp sinuses. In these low lying defects dissection of the inferior margin of the fistula is virtually impossible. Such a case was described by Scott[4] in which an attempt at proximal dissection was unsuccessful. Similar cases in which the fistulas abutted on the arterial valves have been reported by Dodds and Hoyle[5] and have been encountered on two occasions in our experience (Fig 1).

METHOD

With these principles in mind, a series of experiments were carried out in an attempt to produce in dogs a fistula comparable to that seen clinically in aortic septal defects so that techniques for closure might be tested experimentally. Preliminary attempts consisted in the placement of a stab wound at the base of the heart where the walls of the pulmonary artery and aorta are in apposition. Although it was possible to create a fistula in this way, there was moderate to severe dissection of blood between the vessels, and the fistula almost invariably closed in twenty-four to ninety-six hours. This experience had occurred also in the hands of others.[4] Subsequently the following method was evolved.

Utilizing healthy mongrel dogs of unselected weight, anesthesia was induced employing intravenous Nembutal (25 mg. per kilogram body weight) following preoperative medication with morphine sulfate (4 mg. per kilogram body weight). Respiration was maintained using a mechanical insufflator and a cuffed endotracheal tube. The animal was positioned with the left chest uppermost, and it was entered, under sterile conditions, through a short incision in the fourth interspace. The pericardium was opened, and the intrapericardial fat pad overlying the base of the aorta and pulmonary artery was dissected away (Fig. 2, Stage I). By gentle retraction of the pulmonary artery one is readily able to develop the plane between these two vessels down to the root of the aorta. When this point is reached, the origin of the right and left coronary arteries is clearly visualized. A wafer of polyvinyl (Ivalon) sponge, about 0.5 mm. in thickness and 2.0 cm. square, which had been previously soaked in a 4 per cent solution of diacetyl phosphate, was then placed between the root of the aorta and the pulmonary artery; if desired the sponge may be secured by a single stitch placed above it between the adventitial layers of the two vessels to ensure against possible displacement. The pericardium was loosely approximated and the chest closed. Postoperatively, 300,000 units of penicillin and 0.5 Gm. of streptomycin were given for three days. The animals were allowed to recover for a period of about six weeks after which time the fistulas were created at a second operation.

For the second stage, the left chest was reopened through the fourth interspace utilizing the same premedication and anesthesia. The pericardium was opened and retracted with stay sutures. A purse-string suture of 4-0 black silk on a fine Atraumatic needle was placed in the anterior wall of the pulmonary artery, just above the pulmonary valve (Fig. 2, Stage II). The purse-stringed area was then excluded from the arterial lumen by a Satinsky or a curved Potts ductus clamp and incised. A commercial cork borer, 4 to 11 mm. in diameter, was then introduced into the excluded segment of the pulmonary artery and while an assistant controlled the purse-string, the clamp was removed to permit the borer to enter the pulmonary artery. Blood loss during this maneuver was negligible, and gentle traction on the purse-string controls any further bleeding around the borer. The exposed end of the borer is capped with a cork or held with the finger to prevent bleeding. The heart tolerates this manipulation well, and there is no necessity for haste.

At this point the index finger of the left hand is introduced into the transverse sinus to act as a guide Using a rotary motion a defect is then punched out between the contiguous, now firmly adherent walls of the pulmonary artery and aorta If one keeps in mind the fact that the aortic cusps are lower the borer can be angled inferiorly so as to place the defect in almost

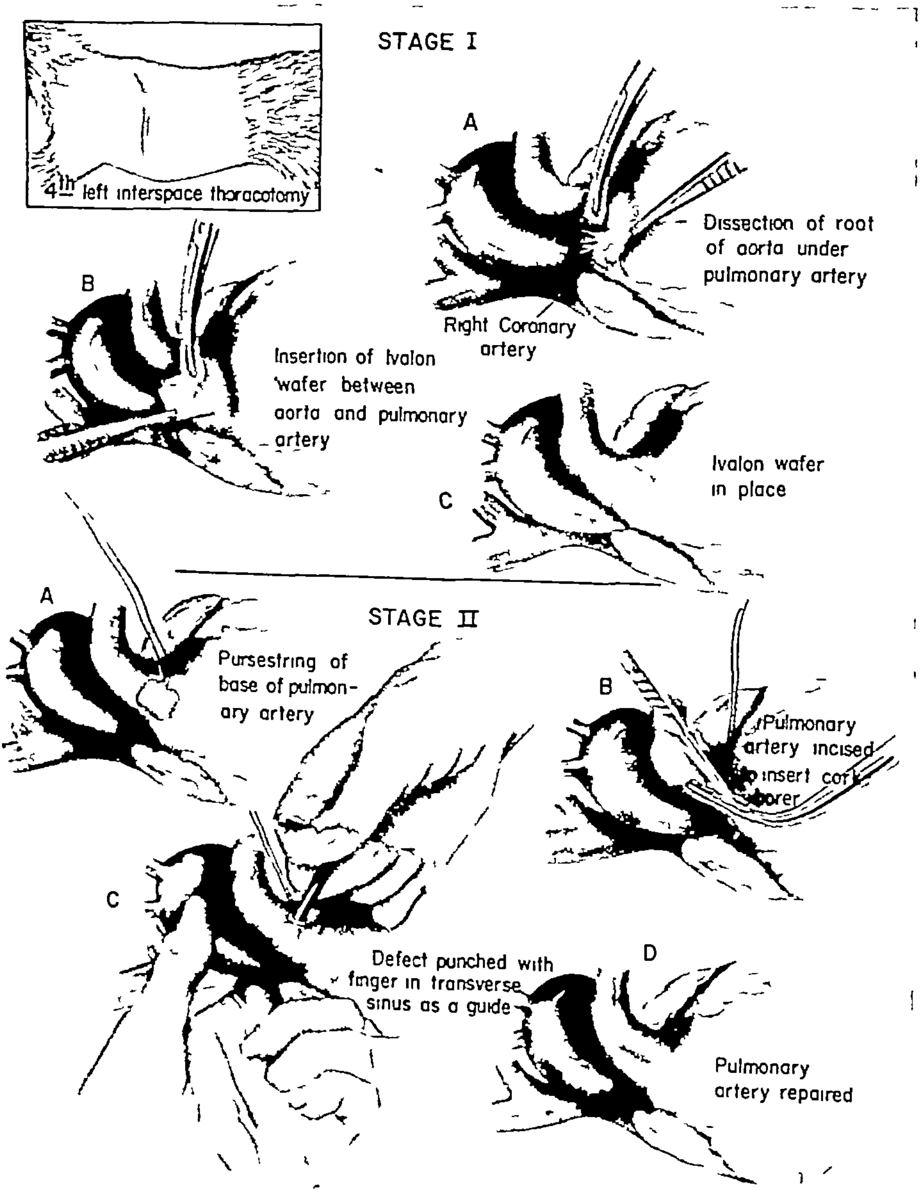
4th left interspace thoracotomy
STAGE I
A
Dissection of root of aorta under pulmonary artery
Right Coronary artery
B
Insertion of Ivalon wafer between aorta and pulmonary artery
C
Ivalon wafer in place
STAGE II
A
Pursestring of base of pulmonary artery
B
Pulmonary artery incised to insert cork borer
C
Defect punched with finger in transverse sinus as a guide
D
Pulmonary artery repaired

Fig 2—Schematic diagram outlining method of creating aorticopulmonary fistulas in two stages (See text)

identical positions just above the valve cusps of each vessel. The finger in the transverse sinus acts as a useful guide and greatly aids in the control of the borer. The creation of the defect can be recognized by the immediate appearance of a marked thrill or by momentarily raising the finger from the exposed end of the borer to allow bright red aortic blood to spurt from the borer shaft. The heart usually manifests a tachycardia as soon as the shunt is created. The cork borer was then carefully withdrawn and the Potts clamp reapplied. A short running suture of 6 0 silk served to close the incision in the pulmonary artery. The chest was then closed, and the animals were observed twice weekly. Murmurs were invariably audible with the stethoscope, and frequently a pronounced thrill could be palpated.

RESULTS

Following some preliminary trials by other methods, nine animals were subjected to the creation of aorticopulmonary fistula by the technique described. As had been the experience of Scott and Sabiston, defects over 5 mm. in diameter were not tolerated, the animals dying of acute heart failure either immediately or early in the postoperative period. In those animals in which the defect was 5 mm. or less, the fistula occasioned no untoward effects and at sacrifice showed no tendency to heal over. The results following creation of aortic pulmonary shunts in these nine animals are indicated in Table I.

TABLE I. PRODUCTION OF AORTICOPULMONARY FISTULAS

DOG NO	DEFECT SIZE (MM.)	RESULT
1003	12	Excellent thrill followed by acute cardiac dilatation and arrest within minutes
959	11	Good thrill followed by cardiac dilatation and fibrillation within minutes
862	11	Died 48 hours, heart failure, defect open
957	8	Died 37 days, heart failure, defect open
871	6	Died 9 days, intrapericardial rupture of fistula with cardiac tamponade
496	5	Died 3½ months, distemper, defect open
774	4	Sacrificed 5 months, defect open
29	5	Sacrificed 3½ months, defect open
36	4	Died 4 months, defect open, endocarditis

Photographs of some of these defects are shown in Figs. 3 and 4. Some of these animals after a period of six weeks, were injected with betahemolytic streptococci in order to compare the susceptibility to endocarditis of these fistulas with those placed elsewhere in the peripheral circulation.[7, 8] This comparison will be the subject of a separate report.

In a few animals, mean pressure studies utilizing a citrate manometer were carried out in the right ventricle and pulmonary artery before the defect was made (at the first stage) immediately after the defect was made (at the second stage) and at the time of sacrifice. These were obtained, utilizing a No. 18 needle by direct puncture of the respective chambers. In addition, in order to obtain objective evidence of the shunt in two animals, Van Slyke

Fig 3—Dog No [illegible] Eight mm defect viewed from the aortic side Animal died of heart failure Note proximity to aortic leaflets

Fig 4—Dog No [illegible] Five mm defect open at three and one half months Note the proximity to aortic cusps and origins of the coronary arteries similar to the congenital variety (Fig 1)

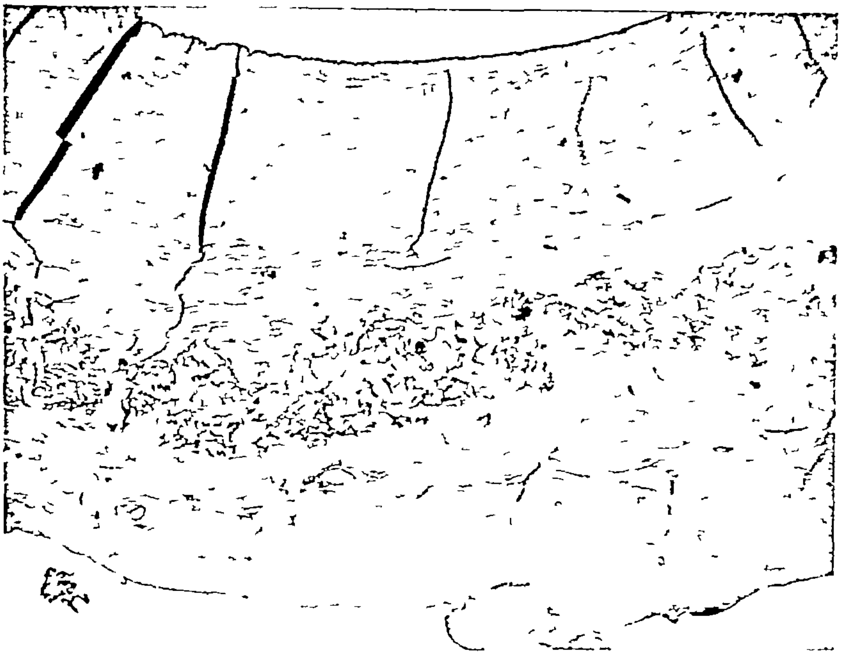

Fig 5.—Low power photomicrograph showing the firm adherence of aorta (above) and pulmonary artery (below). The Ivalon sponge is visible between the two vessels (X75 reduced ⅕.)

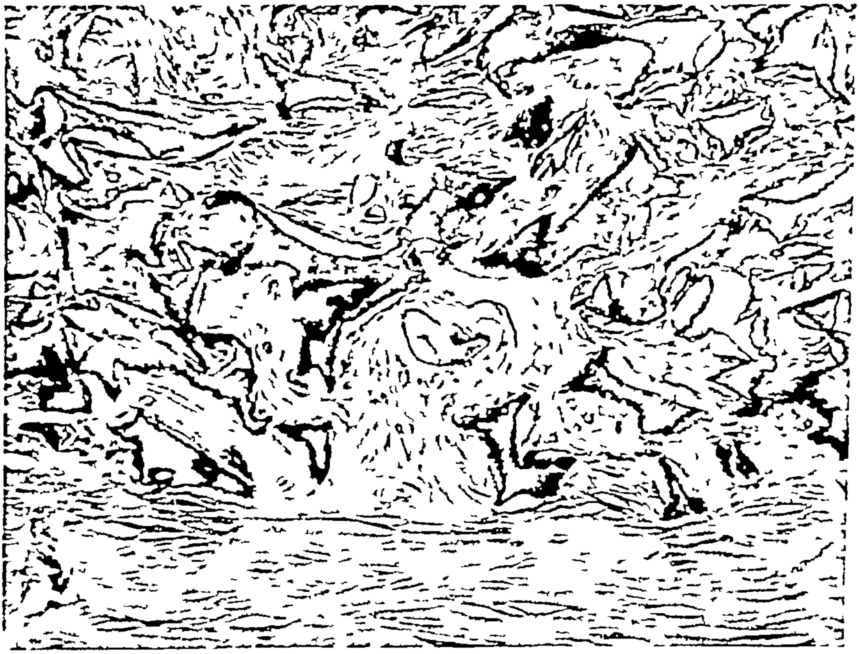

Fig 6.—High power photomicrograph showing dense fibroplasia which has filled the interstices of the Ivalon sponge. (X400 reduced ⅕.)

determinations of oxygen content were carried out on samples drawn simultaneously from the aorta, right ventricle, and the bifurcation of the pulmonary artery. No true estimate of the magnitude of these shunts can be calculated from these figures as the pulmonary artery samples were not true mixed specimens. However, they did provide a definite indication of the presence of left to right shunts. These oxygen contents and pressure values are indicated in Table II.

TABLE II. HEMODYNAMIC ALTERATIONS OF AORTICOPULMONARY FISTULAS

DOG NO.	PRESSURE (CM. OF CITRATE*)						OXYGEN CONTENT (VOLS. PER CENT) AT SACRIFICE		
	AT 1ST STAGE		AT 2ND STAGE		AT SACRIFICE				
	RT. VENT.	PUL. ART.	RT. VENT.	PUL. ART.	RT. VENT.	PUL. ART.	AORTA	RIGHT VENTRICLE	PULMONARY ARTERY
29	20	22	22	29	18	21.5	15.36	8.54	11.71
774	12	12	—	—	16	18	16.84	10.04	13.01
36	14	16	16	18	12	12.5	—	—	—

*The thoracic spine was utilized as a baseline, the animal being positioned on its side.

DISCUSSION

Although the altered physiology and principles of surgical treatment of patent ductus are well documented, the same is not true for aortic septal defects. This, in part, has been the consequence of the lack of an experimental preparation similar to the human anomaly. Wherever one is able to develop a plane of dissection proximal to the fistula, division between clamps would likely be the method of choice; however, in the majority of the clinical instances where this defect exists, the lower margin of the fistula cannot be cleared by dissection because it encroaches on the aortic and/or pulmonary valve cusps. In these cases it would appear that a direct vision approach through the dilated pulmonary artery under total venous inflow occlusion might be considered more feasible.

The use of polyvinyl sponge in inducing a firm fibrous union between the origins of both arteries has permitted the blind creation of defects at the level of the respective valve cusps. This sponge is readily invaded by connective tissue (Figs. 5 and 6) and will permit the creation of a clean defect if a razor-sharp cutting instrument is employed. These defects permit a significant (albeit undetermined) shunt and do not demonstrate any tendency to close. Further studies will be made to determine the long-range effects of this type of fistula upon the pulmonary vasculature and to investigate these effects in relation to the volume of the left to right shunt.

The increased susceptibility of the valves of the heart to bacterial endocarditis with significant arteriovenous shunts has been previously documented.' The circulation in these experimental animals would appear to be subjected to a significant stress as evidenced by the occurrence of a fulminating bacterial endocarditis following intravenous introduction of small numbers of bacteria which are harmless to animals with a normal circulatory system. The valves most affected were those related to the shunt, particularly the pulmonary valve which in some instances was completely destroyed by engrafted vegetations. These changes are shown in Figs. 7 and 8.

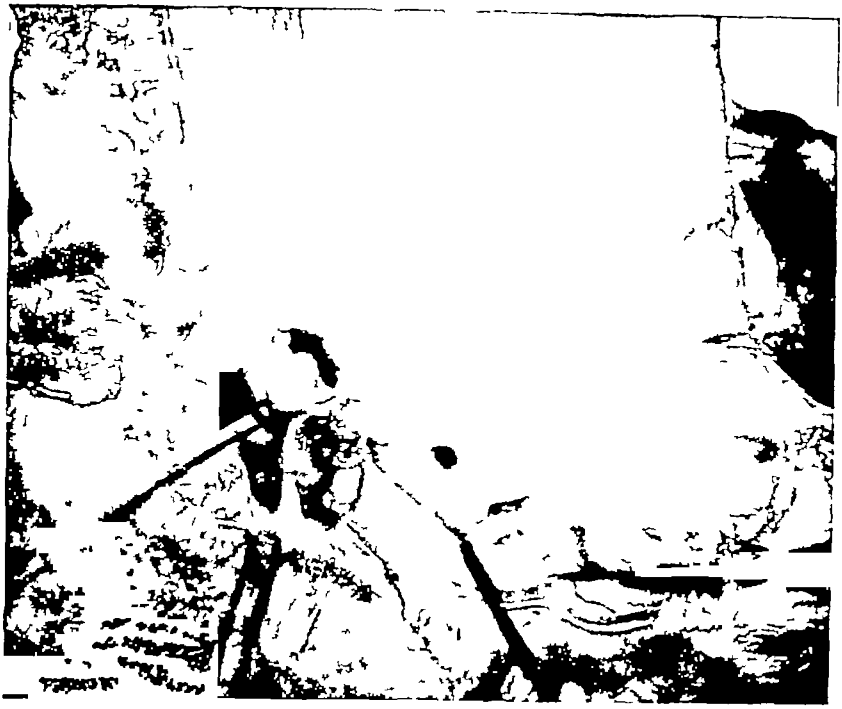

Fig 7 —Dog No 36 Four mm aorticopulmonary defect viewed from aortic side showing bacterial vegetations on the valve cusps

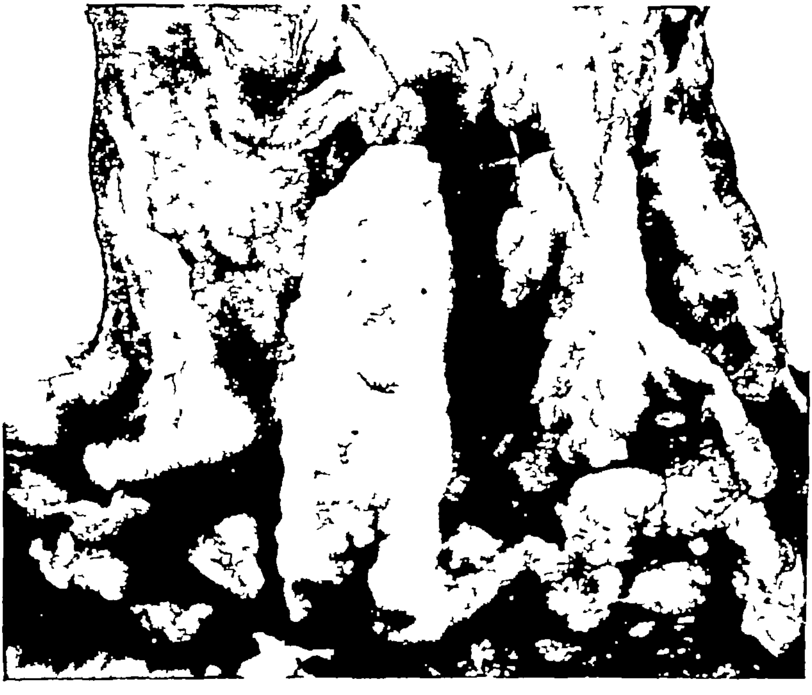

Fig 8 —Dog No 36 Massive vegetations of bacterial endocarditis which have destroyed the pulmonary valve cusps and involved the entire root of the pulmonary artery The aortico-pulmonary fistula is hidden by the vegetations

The pressure studies recorded in Table II are in keeping with the well-established fact that marked increases in pulmonary flow may occur without producing a significant rise in pulmonary artery pressure, unless or until marked reductions of the pulmonary vascular bed (induced by such means as resection of lung tissue or significant arteriolar changes) have occurred to increase resistance to flow It is possible, although controversial that if these shunts were permitted to exist over a period of years, some vascular changes might occur in the pulmonary arterioles with the consequent occurrence of a pulmonary hypertension such as occurs clinically in certain patients with this defect

SUMMARY

Congenital aorticopulmonary fistula, although not a common congenital heart lesion continues to present a surgical problem in its repair Where the lower margin of the defect can be cleared by careful dissection the division of the shunt between clamps will permit corrective ablation However in those instances where the fistula is large and extends to the margin of the arterial valves (which is probably the most common situation) alternate approaches, probably through the pulmonary artery with the circulation temporarily interrupted become necessary An experimental method of creating this latter type of defect has been outlined

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INTRAPERICARDIAL DISSECTION IN RIGHT PNEUMONECTOMY FOR BRONCHOGENIC CARCINOMA

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F HENRY ELLIS, JR , M D ,** ROCHESTER, MINN

PROOF is not yet available to show that resection more radical than that accomplished by ordinary pneumonectomy offers a better chance for cure of bronchogenic carcinoma than does the latter procedure There are reasons for believing, from a theoretic standpoint, that such is true With this in mind, we have executed radical pneumonectomy, as have others, in instances of bronchogenic carcinoma not suitable for lobectomy In time, data will become available to settle the question as to the advantages of this radical procedure in terms of survival rates

Meanwhile, it is important to determine the risk of the more extensive operations, and to standardize the techniques These techniques have been introduced and extended by Allison,[1] by Healey and Gibbon,[2] and by others We previously outlined our experience with radical left pneumonectomy employing intrapericardial dissection [3] Herein our experience to date with right pneumonectomy and intrapericardial dissection is detailed, and an appraisal is made of the operative mortality

ANATOMY

As the pulmonary arteries leave, and the pulmonary veins enter the heart, they receive fibrous projections from the fibrous pericardium, which blend with their adventitia The superior vena cava, as it enters the pericardium, likewise receives such fibrous expansions However, as the inferior vena cava enters directly via the central tendon of the diaphragm it does not receive any fibrous reflection

The serous layer of the parietal pericardium lies on the undersurface of the fibrous pericardium, but at the sites of vessel attachment to the heart the parietal serous layer is reflected to form the visceral serous covering, or epicardium These lines of serous pericardial reflections form two very short mesenteries the arterial mesocardium and the venous mesocardium

The venous serous reflection envelops, with a double membrane, in turn, the inferior vena cava the right pulmonary veins, the superior vena cava, and the left pulmonary veins The attachment of these to the posterior parietal pericardium presents the form of an inverted U, and the resultant cul de sac lying behind the left atrium is known as the "oblique sinus " The double layer of connecting serous pericardium must be incised both above and below the vessel to allow a ligature to be passed around it

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As the inferior aspects of the pulmonary arteries bulge into the serous sac they receive a serous reflection which must be divided anteriorly and posteriorly to free them completely for ligature

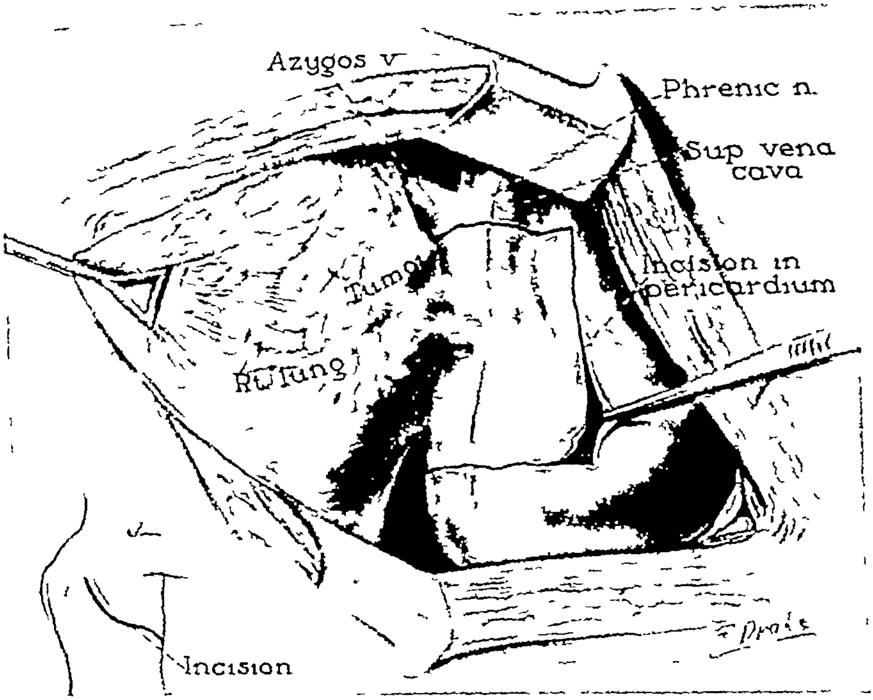

Fig 1 —Initial stage of right pneumonectomy with intrapericardial dissection In many cases the pericardium is incised posterior to the phrenic nerve but when the tumor is encroaching on the pericardium this nerve must be sacrificed

TECHNIQUE

We have used a posterolateral incision through either the fifth interspace or the bed of the resected sixth rib for right pneumonectomy In most of our cases, the patient has been on his left side during operation, however, recently we have carried out the identical procedure while the patient was in the prone position There can be little doubt that the identical operative procedure can be carried out with the patient in either position although the order of the dissection may have to be altered somewhat The following description applies when the patient is in the lateral position

Initially, the entire site of dissection is outlined by incising the mediastinal pleura over the azygos vein and carrying this incision down anteriorly across the superior vena cava and longitudinally opening the pericardium just behind the phrenic nerve If it is opened well posteriorly in this fashion, there is no difficulty with herniation of the heart through the opening postoperatively On occasions however the carcinoma has invaded anteriorly onto the pericardium in such a way that wider removal is necessary and in these instances the pericardium must be opened anterior to the phrenic nerve as shown in Fig 1

A flap of pericardium can then be developed which can be strongly retracted posteriorly to display the superior vena cava above and the lateral aspect of the right atrium below. The superior and inferior pulmonary veins can then be identified intrapericardially and the main right pulmonary artery can be seen to emerge from beneath the superior vena cava. Because of the possible dissemination of tumor emboli through the veins, it has been our practice to secure the veins first whenever possible. The pericardial reflections around the superior pulmonary vein are freed and the vein is doubly ligated on the proximal side flush with the posterior wall of the left atrium and divided between the distal ligature and a clamp placed more distally. The inferior pulmonary vein is generally secured within the pericardium, although, because of its slightly more posterior location, it is not quite as easily exposed. On occasions when the carcinoma is invading well down onto the pulmonary vein area, it has been possible to place a fine tooth Potts curved clamp directly on the "diverticulum" of the posterior left atrial wall into which both right pulmonary veins enter. The veins are clamped distally and disconnected from the atrial wall. The resultant defect in the atrium is then oversewn with interrupted silk sutures.

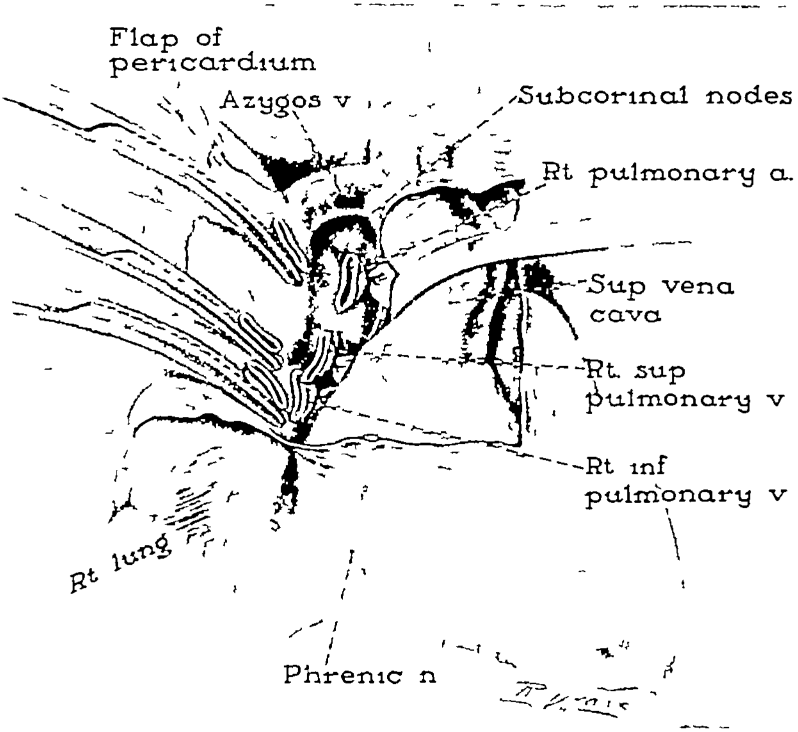

Fig. 2.—The superior and inferior pulmonary veins are secured first. The right pulmonary artery is divided beneath the superior vena cava which is retracted. In practice all pulmonary vessels are secured by a ligature plus a transfixion ligature.

The pulmonary artery is freed from its pericardial reflections beneath the superior vena cava where it is doubly ligated on the proximal side, clamped distally, and divided between the ligatures and the clamp (Fig. 2).

The lung is then retracted anteriorly and the incision of the mediastinal pleura is carried over the azygos vein down, caudally, over the esophagus The right main bronchus is dissected out in such a way that the subcarinal lymph nodes are peeled down so as to be removed along with the specimen The bronchus is cut across flush with the trachea and closed with interrupted silk With traction on the clamp securing the bronchus distally the lung is elevated, the subcarinal lymph nodes and the lymph nodes along the proximal reaches of the left main bronchus are dissected away so as to be removed with the specimen

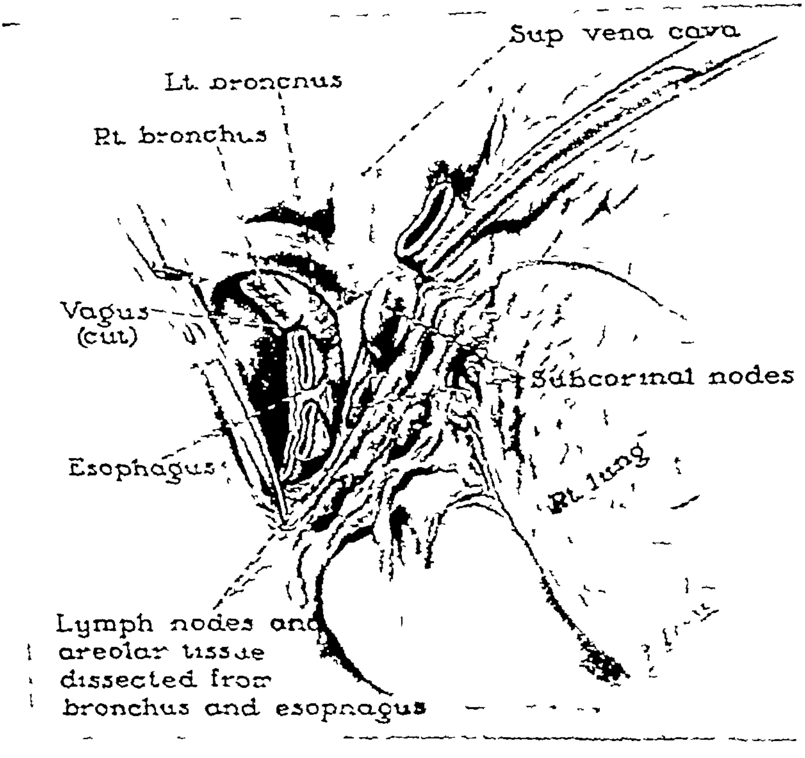

Fig 2 —The lung is now reflected anteriorly The subcarinal lymph nodes and nodes along the upper reaches of the left main bronchus are swept down with the specimen The right bronchus is cut across just distal to the carina. As the lung is lifted away from the mediastinum the mediastinal nodes are dissected away en bloc with the specimen.

Likewise, the lymph nodes lying alongside the adjacent esophagus are dissected up to be removed en bloc with the lung and soft tissue and remainder of the mediastinal lymph nodes The vagus nerve is severed as it emerges from beneath the azygos vein and also severed again distally low in the thorax so that a portion of it is removed with the specimen As this removal of the specimen progresses a portion of the pericardium and soft tissue in this region is likewise dissected away (Fig 3)

At the conclusion of the resection there remains a defect in the pericardium and a defect in the mediastinal pleura in the region of the hilus of the lung The left main bronchus the esophagus and the aorta can all be seen after this en bloc removal of the lung a portion of the pericardium and the mediastinal lymph nodes The bronchial stump is carefully covered with mediastinal pleura and soft tissue The thoracic wall is closed in layers in the usual fashion without drainage

RESULTS

Right pneumonectomy with intrapericardial dissection and removal en bloc of the mediastinal lymph nodes has been done in 32 cases During the same period, left pneumonectomy with intrapericardial dissection, as previously described, has been performed on 49 patients, which makes a total of 81 pneumonectomies done by the intrapericardial operation In this group there have been six deaths during hospitalization, a mortality rate of 7 4 per cent

In the series of 49 patients who underwent left pneumonectomy, two have died—the case of one patient was reported in our previous communiqué,[3] the other patient died of pulmonary embolism Four deaths occurred, however, among the 32 patients undergoing right pneumonectomy with intrapericardial dissection, a mortality rate of 12 5 per cent

Two of these four deaths resulted from respiratory insufficiency in the late postoperative period One death was due to a massive embolus to the left pulmonary artery occurring on the fifth postoperative day The fourth patient died as a result of empyema on the right side and subsequent development of a bronchopleural fistula These data corroborate the impression of others that right pneumonectomy, in general, carries a more significant risk in cases of carcinoma than does left pneumonectomy

In only one case, namely, that of the patient with empyema and late bronchopleural fistula, could the more radical pneumonectomy have possibly been implicated in the patient's death There were no other instances of bronchopleural fistula in this series, however, and it is our impression that, in the fatal case reported, the bronchopleural fistula developed after the empyema and was perhaps secondary to it

It is, of course, impossible as yet to assess the survival rate in these cases Further time and study will be necessary before it is known whether the more extensive operation results in a higher percentage of survivals

DISCUSSION

The operative procedure described can be done safely and its use can extend the resectability of carcinoma of the lung It is not as radical as some procedures described, and we do not deny that a more extensive operation can be done—nor do we deny the possible advantages of such a procedure This is a safe, rational, aggressive mode of attack on bronchogenic carcinoma Whether or not it has a more favorable effect on the survival rate than standard pneumonectomy remains to be determined

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METASTATIC MALIGNANT LESIONS OF THE LUNGS TREATED BY PULMONARY RESECTION

A REPORT OF 43 CASES

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THE modern surgeon has responded to the therapeutic challenge of malignant disease with increasingly bold attempts to extirpate all discoverable malignant tissue. Wide, en bloc resections of primary growths with partial or total removal of adjacent structures have become accepted surgical procedures for cases of extensive malignancy beyond the hope of cure by lesser surgical measures. Excision of distant metastatic lesions, at first approached as an interesting experiment, has gradually evolved into a defensible but still highly controversial procedure. Pulmonary resection for metastatic lesions probably represents the greatest experience with the surgical excision of distant metastatic lesions. The general acceptance of this procedure, however, awaits a careful assessment of its accrued benefits. These include the palliation afforded, the retardation of the rate of spread of the disease, and the incidence of "cure" effected by the removal of a presumably solitary metastatic lesion. The answers are not to be shortly forthcoming. Experience is still limited and relatively brief. As in all studies involving many types of malignant disease, the extreme variability in the behavior of the individual types of tumors introduces a troublesome complexity. These factors inevitably delay final judgment of pulmonary resection as an established procedure for the treatment of metastatic malignant disease.

In 1950, Seiler, Clagett, and McDonald[1] reviewed the experience at the Mayo Clinic with the treatment of pulmonary metastatic lesions by resection. This report is an extension of that study.

MATERIAL AND METHOD OF STUDY

This study comprises a review of forty-three cases in which pulmonary resection was performed at the Clinic as a definitive procedure for a metastatic tumor of the lung. It does not include cases in which the pulmonary operation was limited to a biopsy of the intrathoracic lesion. Ten of the forty-three cases were previously reported by Seiler, Clagett, and McDonald. The patients of this latter group surviving at the time of their report have been further traced.

Twenty-three of the patients were male and twenty female. The relative similarity of incidence in the sexes is in distinct contrast to the preponderance of males among the patients undergoing pulmonary resection for bronchiogenic carcinoma.

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At the Clinic the first pulmonary resection for metastatic malignant lesions was performed in August, 1941, on a patient who had, 3 years previously, undergone nephrectomy for hypernephroma This study includes all the cases in which removal of metastatic pulmonary lesions was performed prior to 1952 The procedure has been increasingly utilized during recent years During 1951, pulmonary resection was performed 13 times for metastatic pulmonary lesions

The ages of the patients at the time of the pulmonary resection varied in this series from 6 to 67 years (Table I) The operations for the primary lesions had been performed between the ages of 6 and 66 years Fifty-eight per cent of the pulmonary operations were performed on patients in the fifth and sixth decades of life

TABLE I. AGE OF PATIENTS WITH METASTATIC MALIGNANT LESIONS TREATED BY PULMONARY RESECTION

AGE IN YEARS	INITIAL OPERATION		PULMONARY OPERATION	
	NUMBER	PER CENT	NUMBER	PER CENT
0 9	2	4 8	1	2 3
10 19	1	2 4	1	2 3
20 29	6	14 3	4	9 3
30 39	8	19 0	6	14 0
40-49	14	33 3	12	27 9
50 59	8	19 0	13	30 2
60 69	3	7 2	6	14 0
Total	42*	100 0	43	100 0

*Excludes one patient without resection of primary growth see text

Follow-up studies were obtained on forty-two of the forty-three patients One patient, a woman whose pulmonary lesion was secondary to an adenocarcinoma of the uterus, could not be located following her dismissal from the Clinic Among the patients known to be living at the time of this study, the shortest period following operation was 14 months and the longest period 78 months Follow-up studies applied to eighteen of the patients over a 3-year period and to eleven of them over a 5-year period

Operations for the primary lesions were all curative in objective, and no detectable malignant tissue remained after completion of the operation In one case, reported previously by Seiler and associates,[1] a patient with an adenocarcinoma of the colon underwent pulmonary resection prior to removal of the primary growth In one other case, the secondary nature of the pulmonary lesion was discovered after pathologic examination of the surgically removed lung The patient succumbed before the location of the primary growth could be discovered The primary lesion was found at necropsy [*] In two patients, the initial growth was treated by roentgen therapy following biopsy rather than by surgical excision

ANALYSIS OF DATA

Symptoms.—Twenty four patients did not complain of any significant pulmonary symptoms prior to removal of their metastatic tumors The commonest complaint among the remainder was a cough, which was present among four teen of the patients. In ten of this group the cough was productive of sputum. Hemoptysis was noted by eight of the patients. Three patients complained of pain, two of dyspnea, and one of wheeze.

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[*] Another patient underwent two pulmonary resections for metastatic pulmonary lesions the first a lobectomy and the second 37 months later a local excision

In the majority of patients the onset of pulmonary symptoms was not of itself a factor in the detection of the pulmonary metastasis, since most patients reported regularly for follow-up examinations. However, in twelve patients whose primary lesions had been removed from 3 to 15 years previously, concern about pulmonary symptoms provided the stimulus for seeking medical consultation.

Roentgenologic Characteristics.—All patients in this study presented roentgenologic evidence of a nonobstructive pulmonary mass lesion. The size of the lesions varied from 1 to 7 cm. in diameter. With two exceptions the lesions were solitary. In both of these cases the appearance was that of satellite nodules rather than widely separated or disseminated multicentric lesions. The characteristic lesion was peripheral in location rather than situated deeply within the lung. It was round rather than oval or irregular in shape. Its border was distinct rather than hazy, its shadow dense, and its consistency homogeneous. Small lesions naturally, were less likely to present a distinct border and heavy shadow than large lesions. No lesions in this group showed roentgenologic evidence of central necrosis or calcification. Except in two cases no detectable pulmonary lesion was present at the time of operation for the primary tumor; thus the appearance of a mass in the lung was prima facie evidence of a growing lesion.

Cytologic Examination of the Sputum.—Many of the patients underwent pulmonary resection prior to the establishment of cytologic examination of the sputum as a standard procedure, so that the number of patients studied by this means was necessarily small. Eleven patients had at least one examination of the sputum for malignant cells. Atypical cells were found in one patient. In two cases, an unequivocal diagnosis of malignant cells was reported. The results of examination for eight patients were negative.

Bronchoscopic Examination.—For many years at the Clinic it has not been customary to perform bronchoscopy uniformly on patients because of the sole finding of a pulmonary lesion on the roentgenogram. Since peripheral lesions rarely can be visualized by bronchoscopy, this procedure in the absence of other indications for bronchoscopy, was not performed on the majority of these patients.

Preoperative bronchoscopy was performed on eleven patients, only three of whom failed to show some abnormality related to their metastatic lesion. In five cases, tissue obtained by biopsy was demonstrated to be malignant. The tissue from another mass showed only inflammatory changes. In another patient the right lower lobe bronchus was narrowed. Bronchoscopy revealed blood coming from the affected lobe in another.

Pathologic Nature of Primary Tumor.—The metastatic tumors encountered in this group of patients arose from a wide variety of primary growths (Table II). Thirty-two of the tumors were classed as carcinomas. This group included the cases of teratoma of the testis, mixed tumor, and hemangioma. Eleven of

TABLE II. TYPE OF PRIMARY TUMOR FOR WHICH PULMONARY RESECTION OF THE METASTATIC LESION WAS CARRIED OUT

TYPE OF PRIMARY TUMOR		CASES
Carcinoma		32
Adenocarcinoma of rectum	4	
Adenocarcinoma of colon	4	
Adenocarcinoma of jejunum	1	
Adenocarcinoma of uterus	1	
Adenocarcinoma of ovary	2	
Adenocarcinoma of breast	2	
Cylindroma of salivary gland	1	
Cylindroma of nasal fossa	1	
Mixed tumor of jaw	1	
Hypernephroma	3	
Squamous-cell epithelioma of skin	1	
Squamous cell epithelioma of larynx	1	
Squamous cell epithelioma of cervix	2	
Melanoma	3	
Hemangio endothelioma	1	
Teratoma of testis	4	
Sarcoma		11
Fibrosarcoma	6	
Osteogenic sarcoma	3	
Giant-cell tumor of bone	1	
Ewing's tumor	1	

the tumors were classed as sarcomas. The commonest tumor was adenocarcinoma of the bowel, the primary lesion of which was located in the jejunum in one patient, in the colon in four patients, and in the rectum in four patients. Teratoma of the testis also occurred 4 times. Hypernephroma and melanoma were each encountered 3 times. There were two cases each of adenocarcinoma of the ovary, adenocarcinoma of the breast, and squamous-cell epithelioma of the cervix. Adenocarcinoma of the uterus, cylindroma of the salivary gland and of the nasal fossa, mixed tumor of the jaw, squamous cell epithelioma of the skin, squamous cell epithelioma of the larynx, and hemangioma were each encountered once. The commonest of the sarcomas was fibrosarcoma, which was found in six patients. Osteogenic sarcoma accounted for three cases and giant cell tumor and Ewing's tumor each for one.

Time Interval Between Removal of the Primary Tumor and Removal of the Pulmonary Metastatic Growth.—In two instances the pulmonary metastasis was removed before a primary growth was excised. The interval between the two procedures varied in the remaining patients from 2 to 270 months. The pulmonary resection was performed between 1 and 5 years following removal of the primary growth in twenty-five of the forty-three cases.

Type of Operation.—All forms of pulmonary resection were employed in this group of patients. Lobectomy was most frequently the procedure of choice, being utilized 26 times. Pneumonectomy was performed for twelve of the patients. Local excision, including wedge resection, was used 4 times (once as a second resection after lobectomy and a recurrence of the metastatic lesion), and segmental resection was used twice. There has been a trend toward more conservative resection of pulmonary tissue for metastatic tumors. Pneumonectomy was performed in 28 per cent of all cases in the series, but in only 15 per cent of the cases in which operation was performed during 1951 On the other hand, the local excisions and segmental resections were all carried out during 1950 and 1951

Survival Periods—The pertinent data for each case are summarized in Table III One patient failed to reply to follow-up letters after leaving the Clinic Another patient succumbed 1 month after pulmonary resection while still in the hospital and represented the only hospital death in the group The survival statistics are based on the remaining forty-one patients who were successfully followed (Table IV)

The longest period of survival in the series was for more than 6 years in three cases Two of these patients were still living 78 and 77 months after operation while the third had succumbed 81 months postoperatively

Among the forty-one patients thirty (73 2 per cent) survived for longer than 1 year Twenty patients underwent operation at least 3 years prior to the close of this study, and two of these were not traced for as long as 3 years Six (33 3 per cent) of the eighteen traced patients were living 3 or more years after operation Eleven patients were followed for at least 5 years after operation three of them (27 3 per cent) survived this interval

The presence or absence of preoperative pulmonary symptoms had little, if any, prognostic bearing Since most of the patients underwent operation in recent years, only 1-year survival rates will be calculated when comparing various factors Of the total forty-one patients, twenty-three were asymptomatic of whom seventeen (73 9 per cent) lived 1 year or more after operation Among the eighteen patients with preoperative pulmonary symptoms, thirteen (72 2 per cent) lived 1 year or more The mean interval between the operations for the removal of the primary and metastatic tumors was 36 months for the asymptomatic group and 59 months for the group with symptoms Thus, the presence of pulmonary symptoms should not in itself deter the decision for resection of pulmonary metastasis

In general, the larger lesions, as measured by roentgenographic means, were associated with shorter survival periods The 1-year survival rate for the larger lesions was 50 per cent as compared with 75 per cent for the smaller lesions Measurements were made on only sixteen patients, eight in each group The patient with the largest metastatic lesion (7 cm in diameter) died 10 months after operation There were only two patients in the series whose tumors appeared multicentric on the roentgenograms These died 6 and 10 months postoperatively

Exfoliated malignant cells were found in the sputum in only three cases In addition there were eight cases with negative results of sputa examinations These groups are obviously too small to permit any conclusion regarding the prognostic significance of exfoliation of cells from the metastatic lesions

A review of the bearing of the pathologic nature of the tumor on the survival period permits few if any unqualified conclusions Among the eleven patients with sarcoma six (54 5 per cent) lived 1 year or more after operation Of the thirty patients with carcinoma, twenty-four (80 0 per cent) lived 1 year or more after operation Thus there is a somewhat more favorable outlook for patients with carcinoma than for those with sarcoma

TABLE III PULMONARY RESECTION FOR METASTATIC MALIGNANT LESIONS DATA ON 43 CASES

CASE	PRIMARY LESION, TYPE AND SITE	TIME INTERVAL (MONTHS) FROM REMOVAL OF PRIMARY TUMOR TO PULMONARY RESECTION	OPERATION	MONTHS AFTER PULMONARY RESECTION: WITHOUT RECURRENCE	UNTIL RECURRENCE	UNTIL DEATH
1	Adenocarcinoma, rectum	48	Lobectomy		12*	
2	Adenocarcinoma, rectum	24	Lobectomy		12	16
3	Adenocarcinoma, rectum	12	Lobectomy			12
4	Adenocarcinoma, rectum	51	Lobectomy		8	12
5	Adenocarcinoma, colon	0	Pneumonectomy		20	24
6	Adenocarcinoma, colon	72	Lobectomy			12
7	Adenocarcinoma, colon	60	Lobectomy	40		
8	Adenocarcinoma, colon	36	Pneumonectomy			12
9	Adenocarcinoma, jejunum	0	Pneumonectomy			1
10	Adenocarcinoma, uterus	36	Lobectomy	No data		
11	Adenocarcinoma, ovary	180	Pneumonectomy	14		
12	Adenocarcinoma, ovary	48	Lobectomy	78		
13	Adenocarcinoma breast	120	Lobectomy	45		
14	Adenocarcinoma, breast	48	Segmental resection	21		
15	Cylindroma, salivary gland	60	Lobectomy	20		
16	Cylindroma, nasal fossa	12	Lobectomy		12	19
17	Mixed tumor, jaw	270	Pneumonectomy		5	12
18	Hypernephroma	37	Pneumonectomy		66	81
19	Hypernephroma	48	Pneumonectomy	31		
20	Hypernephroma	2	Lobectomy			1
21	Squamous cell epithelioma, thumb	48	Lobectomy	24		
22	Squamous cell epithelioma, larynx	108	Lobectomy		5	21
23	Squamous cell epithelioma, cervix	24	Lobectomy	25		
24	Squamous cell epithelioma, cervix	48	Lobectomy	26		
25	Melanoma, right shoulder	36	Lobectomy			6
26	Melanoma, left shoulder	48	Segmental resection			7
27	Melanoma, left forearm	48	Lobectomy		3	4
28	Hemangio endothelioma	120	Pneumonectomy			31
29	Teratoma, testis	12	Lobectomy			6
30	Teratoma, testis	36	Pneumonectomy		2	4
31	Teratoma testis	15	Lobectomy		18	21
32	Teratoma, testis	12	Lobectomy	39		
33	Fibrosarcoma, right chest wall	6	Pneumonectomy			10
34	Fibrosarcoma, right leg	132	Lobectomy		36	
		169†	Local excision	40		
35	Fibrosarcoma, back	48	Lobectomy			3
36	Fibrosarcoma, arm	2	Local excision			10
37	Fibrosarcoma, back	36	Lobectomy		9	12
38	Fibrosarcoma elbow	144	Lobectomy		6	18
39	Osteogenic sarcoma, os calcis	60	Lobectomy		3	11
40	Osteogenic sarcoma tibia	72	Pneumonectomy			15
41	Osteogenic sarcoma scapula	48	Pneumonectomy	19		
42	Giant cell tumor tibia	18	Local excision	28		
43	Ewing's tumor, humerus	7	Local excision			8

*Living 23 months

†Patient underwent second pulmonary resection for recurrence 37 months after first pulmonary resection Free from further recurrence 40 months later 77 months after first pulmonary resection

The variation in survival period among patients with pathologically similar tumors was great The shortest survival period of a patient with fibrosarcoma was 3 months, yet one was living without recurrence 77 months after operation[*]

TABLE IV SURVIVAL PERIODS* FOLLOWING PULMONARY RESECTION FOR A METASTATIC MALIGNANT LESION

SURVIVAL PERIOD, YEARS	CONDITION AS OF LAST REPORT	
	LIVING	DEAD
Less than 1	0	11
1, but less than 2	5	12
2, but less than 3	5	2
3, but less than 4	3	0
4, but less than 5	0	0
5, but less than 6	0	0
6, but less than 7	2	1

*Exclusive of one untraced patient and one patient who died in the immediate postoperative period

Three of the six patients with fibrosarcoma lived for 1 year or more One of the three patients with osteogenic sarcoma was living 19 months postoperatively, while the other two succumbed at 11 and 15 months The patient with a giant-cell tumor was living 28 months after operation, while the child with Ewing's tumor had died in 8 months All three patients with melanomas died in 7 months or less The patient with hemangio endothelioma survived for 31 months Squamous-cell epithelioma carried a more favorable prognosis With the exception of the patient whose lesion arose in the larynx, all were living at the completion of this review The periods elapsed were 25 and 26 months for two patients with lesions of the cervix, and 24 months for the one with the thumb lesion The patient with squamous-cell epithelioma of the larynx died 21 months after operation Of the four patients with carcinoma of the rectum all had recurrences within a year and two had died within a year The outlook for the four patients with carcinoma of the colon was somewhat more favorable One was surviving 40 months after operation without evidence of recurrence The others had died at intervals of 24, 12, and 12 months after removal of the metastatic growth The patient with carcinoma of the jejunum died before the primary growth was removed Both patients with carcinoma of the ovary survived, one being alive without recurrence 14 months, and the other, 78 months following operation In two of the four cases of teratoma of the testis, the patients had died within 6 months In contrast, another was living 39 months after operation Two of the three patients with hypernephroma had favorable results One lived 81 months after operation, while the other was free of apparent recurrence after 31 months The third patient died 1 month after pulmonary resection Of the two patients with cylindroma, the patient with the nasal-fossal lesion survived 19 months, while the one with the salivary gland lesion was living 20 months following its removal The patients with the mixed tumor of the jaw lived only 12 months Both patients with adenocarcinoma of the breast were free of any evidence of recurrence 21 and 45 months after removal of the pulmonary metastatic lesion

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[*] This latter patient presented one of the most remarkable histories of the group A woman 20 years of age in 1946 at the time of her right lower lobectomy for metastatic fibrosarcoma had previously in 1935 and again in 1939 had the primary and a recurrent lesion excised from the right leg A local recurrence was again excised 1 month after pulmonary resection In 1949 two nodules of metastatic tissue were removed by local excision from the right upper lobe One month later the right leg was amputated through a level in the lower part of the femur for further recurrent local tumor In March 1953 she reported that she was in excellent health had married and had a child 9 months old

The interval between the removal of the primary and metastatic tumors appeared to influence the chances for survival, that is, the greater the interval, the better the survival Of the seventeen patients whose metastatic tumors were removed during an interval of 3 years or less following excision of the primary growth, nine (52 9 per cent) lived 1 year or more following operation Of the twenty-four patients whose metastatic tumors were removed more than 3 years after the primary operation, twenty-one (87 5 per cent) lived 1 year or more following operation

The pulmonary resections consisted of pneumonectomies, lobectomies, and local excisions and segmental resections Twelve patients were treated by pneumonectomy, and of these, one patient died in the hospital Of the remaining eleven patients, nine (81 8 per cent) lived 1 year or more following operation Lobectomy was performed 26 times One patient was untraced Among the twenty-five traced patients, nineteen (76 0 per cent) lived 1 year or more following operation Local excisions and segmental resections were carried out on the remaining five patients (excluding the patient whose second pulmonary resection consisted of local excision) Three died within 12 months following thoracotomy, while the other two were without evidence of recurrence 21 and 28 months later

COMMENT

The exact value of pulmonary resection for metastatic tumors remains difficult to assess solely on the basis of survival statistics The degree of palliation afforded each of these patients likewise was not measurable Few of these patients manifested truly disabling pulmonary symptoms Doubtless, pulmonary resection spared many of them this dreaded terminal distress, while still others were relieved of the constant reminder of the presence of a malignant lesion in the guise of a persistent cough, hemoptysis, or chest pain Criticism of the worth of the procedure should always be tempered by awareness of these often overlooked benefits of removal of the secondary tumor

Facing the clinician and the surgeon contemplating exploratory thoracotomy in a patient who has previously been treated for malignant disease is the real possibility that the pulmonary lesion may be totally unrelated to the earlier disease Regardless of one's opinion of the value of resection of metastatic tumors, there exists this disquieting possibility should the decision be made against operation Further, the low mortality rate (2 per cent) for the patients in this series provides no support for avoiding exploration

The number of patients followed for 3 and 5 years is yet too small to utilize these traditional survival figures in discussion of this procedure The figures of 33 per cent and 27 per cent respectively, for 3 year and 5 year survival periods in this study, while in themselves respectable values, are consequently of limited significance

Criteria for judging the advisability of operation remain obscure In general the chances of "cure" are slightly greater for patients with small lesions that have been discovered more than 3 years following removal of the primary growth than for other patients No great difference was found in the survival among patients with carcinoma and sarcoma Patients with melanoma, teratoma of the testis, and carcinoma of the rectum apparently received less benefit than certain others In contrast, the outlook was relatively favorable for patients with squamous cell carcinoma of the skin and cervix, adenocarcinoma of the colon, ovary, and breast, and hypernephroma A decision based solely on the pathologic nature of the parent tumor, however, is fraught with considerable hazard because of the occasional "cure" obtained even with highly lethal tumors Such a case is that of the patient with metastasis, secondary to a teratoma of the testis, who was alive without recurrence 39 months after its removal

The extent of the pulmonary resection did not in itself appear to be a factor in the length of survival Conservative resections may have more applicability for metastatic tumors than for bronchiogenic carcinoma, since the former are less likely to spread by lymphatic channels In addition, choice of the less disabling procedure finds further support in the fact that the value of pulmonary resection for metastatic disease remains unestablished

The results of this study would appear to justify the continuance of pulmonary resection for metastatic malignant lesions of the lungs The palliation offered is noteworthy, and the prolongation of life is frequently gratifying

REFERENCE

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EXFOLIATIVE CYTOLOGY AND PULMONARY CANCER

A Histopathologic and Cytologic Correlation

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THE value of cytology as an aid in the diagnosis and perhaps earlier detection of pulmonary cancer has been well established The appearance, practical disappearance, and then reappearance of cytology as a diagnostic tool was brought out in the reviews of the history of cytology[6, 14, 29] Numerous reports have appeared in the literature in the last decade, pointing out the degree of success and failure of sputum and bronchial washings Success has varied Iversen[17] and Liebow and co-workers[19] reported less than 50 per cent positive cytologic examinations in histologically proved lung cancers In the intermediate group, 61 to 74 per cent positive smears has been reported[4, 16, 22, 33] More enthusiastic reports[6, 23, 29] show between 80 to 90 per cent positive results *It should be pointed out that O'Keefe[23] concerned himself entirely with bron*chial washings with 88 6 per cent positive smears in 307 proved pulmonary cancers

That the examination of pulmonary secretions for cancer cells is valuable is not doubted But, what are the limitations of this procedure? What information other than the report of positive, suspicious, or negative is gained by cytologic examinations? Segments of these two questions have been examined by several writers The relationship between cytology and histologic type of lesion and between cytology and location of the lesion has been explored[5, 15, 19, 20, 24, 25, 27] Correlation between resectability and cytology has been mentioned by different writers[15, 16, 32] O'Keefe[23] makes an observation concerning cytology, bronchial biopsies, and cancer in pulmonary lymph nodes With a positive cytologic report and a positive bronchial biopsy, the lymph nodes were positive in approximately 50 per cent of 21 cases A negative bronchial biopsy and a positive cytologic examination yielded two out of eighteen cases with positive lymph nodes

MATERIAL AND METHOD

In an attempt to evaluate the two questions, we have studied 501 histologically proved pulmonary cancers and their cytologic examinations These cases were admitted to Barnes Hospital between July 1948, and April 1, 1953 In each case at least one sputum or bronchial secretion was studied for neoplastic cells There has been no selection of cases on the basis of an

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optimum number of examinations. Our method of collection of sputa, preparation of smears, review of slides and reporting of results has been previously outlined.[16]

For this study all of the positive smears and the suspicious smears in cases without a positive smear were reviewed. A representative smear from cases with negative cytology was reviewed. This was done by one of us (D. F.). The histologic typing of the smears was done (by D. F.) and checked (by H. J. S.). The typing was done without knowledge of the pathologic diagnosis. All of the histologic sections from each of the cases were reviewed by two of us (H. J. S. and L. V. A.). Our cases fell into the histologic cell type and sex grouping as generally reported in the literature[2, 8] (Table I). We vary slightly with other writers[5, 20, 24, 25] in that they had a greater number of undifferentiated carcinomas and fewer squamous-cell carcinomas than did we. One notable deviation in our group was the 38.9 per cent occurrence of primary adenocarcinoma of the lung in the female. This figure is higher than usually reported.

TABLE I. HISTOLOGIC TYPE AND SEX DISTRIBUTION OF CASES

TYPE	TOTAL		MALE		FEMALE	
	NO.	PER CENT	NO.	PER CENT	NO.	PER CENT
Epidermoid carcinoma	269	53.7	252	94.6	17	6.4
Undifferentiated carcinoma	143	28.5	136	95.1	7	4.9
Adenocarcinoma	36	7.2	22	61.1	14	38.9
Bronchiolar carcinoma	4	0.8	2	50.0	2	50.0
Bronchial adenoma	11	2.2	7	63.6	4	36.4
Metastatic cancer	29	5.8	15	51.7	14	48.3
Others	9	1.8	7	77.7	2	22.3

Among the 501 cases there were 318 bronchial biopsies, 95 other biopsies, 163 pneumonectomies, 35 lobectomies, 126 thoracotomies for exploration, and 35 autopsy examinations contributing to tissue confirmation of cancer. In each of the cases at least one sputum or bronchial washing was studied for cancer cells. Thus there were 905 sputum examinations for 424 of the cases, and 364 bronchial washings for 343 cases. As would be expected, many cases had both types of examination. The total of cytologic studies in this series was 1,269. During the time period covered in this paper, there were 4,992 sputa and bronchial washings examined in the Barnes Hospital Cytology Laboratory. Including the positive smears used in this study, there were 483 positive sputa and bronchial washings among the 4,992 specimens. These were made up of 342 positive sputa and 141 positive bronchial washings. The positive reports represent 9.6 per cent of all examinations (approximately one in ten examinations). There have been no false-positives between May, 1951 and the preparation of this manuscript, May, 1954.

Breakdown of the cases in this series, as to their cytologic diagnosis yielded 243 positive, 53 suspicious and 205 negative cytologic examinations. On review of the suspicious and negative smears, 47 were changed to positive and 12 negative smears changed to suspicious. The cause for change in the diagnosis of the smears was the result of a combination of conservatism at the time of the original examination and was undoubtedly tempered by the knowledge on the part of the reviewer that the case had proved to be cancer. Including the changes, there are 290, 28, and 183 cases with positive, suspicious, and negative cytologic examinations, respectively (Table II). Percentagewise, 57.8 per cent of the cases had a positive cytologic report, 5.7 per cent suspicious, and 36.5 per cent negative.

TABLE II CYTOLOGIC DIAGNOSES IN 501 CASES OF HISTOLOGICALLY PROVED CARCINOMA

Cases cytologically positive		243
Cases cytologically suspicious		53
On review changed to positive	37	
On review remained suspicious	16	
Cases cytologically negative		205
On review changed to suspicious	12	
On review changed to positive	10	

Of the 318 bronchial biopsies, a diagnosis of cancer could not be made on 107 (33.7 per cent). A diagnosis of cancer was made on 211, or 66.3 per cent. These two groups were divided into operable and inoperable cases. Operable cases were considered as those in which a pneumonectomy or lobectomy was performed. It is readily apparent from study of Table III that inoperable cases yield a higher percentage of positive biopsies than do operable cases. Only *28.0 per cent* of the operable cases had a positive bronchial biopsy. An earlier report on a smaller number of cases from our hospital indicated 36 per cent positive bronchial biopsies in resectable cases. Approximately 59 per cent of pneumonectomies and lobectomies reported by Woolner and McDonald[32] in 1949 had positive bronchial biopsies. Our results for total positive biopsies compare closely with those of several other writers.[5, 20, 24, 31, 32] Their percentage of positive bronchial biopsies ranges from 63 per cent to 76 per cent. Below these figures are those of Herbut and Clerf[12] (42.1 per cent), O'Keefe, (33.8 per cent), and Gibbon and associates,[9] (24 per cent).

TABLE III BIOPSIES AND THEIR RELATIONSHIP TO OPERABILITY

	BRONCHIAL BIOPSIES	OTHER BIOPSIES
Negative for cancer	107 (33.7%)	18 (19.0%)
Operable	47 (43.9%)	4 (22.3%)
Inoperable	60 (56.1%)	14 (77.7%)
Positive for cancer	211 (66.3%)	77 (81.0%)
Operable	59 (28.0%)	3 (3.7%)
Inoperable	151 (72.0%)	74 (96.3%)
Total	318	95

To obtain the 318 biopsies, 489 bronchoscopic examinations were performed in 459 of the cases. Forty-two of the patients were not examined bronchoscopically. No biopsy was taken in 171 of the bronchoscopic examinations. All but 29 had bronchial washings. The 171 were divided into groups "normal bronchoscopic examination" and "deformity seen" (Table IV). The number of bronchial washings and sputa were tabulated under these headings. The percentage of positive sputa and bronchial washings for this group was below that for the entire series, from 0.0 to 5 per cent for sputa and 4 to 15 per cent for bronchial washings. This was particularly true when compared with cytologic examinations accompanied by positive bronchial biopsies This would be expected when the tumor was in reach With a normal bronchoscopic examination there was a higher percentage (27 8 per cent) of positive bronchial washings than with observable deformity In the latter group the percentage of positive bronchial washings is 16 2 per cent

TABLE IV CASES WITH NO BRONCHIAL BIOPSY

	SPUTA (TOTAL NUMBER, NOT CASES)				BRONCHIAL WASHINGS (TOTAL NUMBER = 1 PER CASE)			
	NEGATIVE	SUSPICIOUS	POSITIVE	NO SPECIMEN	NEGATIVE	SUSPICIOUS	POSITIVE	NO SPECIMEN
No bronchoscopic examination (42 cases)	63	3	21					42
Normal bronchoscopic examination (127 cases)	132	18	58 (27 8%)	29	70	7	27 (27 8%)	23
Deformity seen (44 cases)	55	5	17 (22 0%)	6	28	3	6 (16 2%)	7

Note Only the percentage of positive cytologic diagnoses is computed It is based on the number of examinations in each of the three categories Sputum and bronchial washings are calculated separately

Sputa were positive in 27 8 and 22 0 per cent respectively If the bronchi appeared normal to examination, the percentage of positive sputa was comparable to that of the entire group reviewed (501 cases) Sputa from those cases with no bronchoscopic examination were positive in 24 1 per cent O'Keefe was able to diagnose 30 6, or 94 cases, with entirely normal bronchoscopic findings by means of bronchial aspirate The number of aspirations per case is not given Although we anticipated a higher percentage of positive cytologic examinations than was obtained in the group of "deformities" this was not the case The deformities ranged from hyperemia to stenosis We are unable to explain this finding unless compression of a bronchus prevent procurement of a satisfactory washing *The fact that is important however is that with no bronchial biopsy and a normal to near normal bronchial tree one out of four cytologic examinations will be positive*

Ninety five "other" biopsies were obtained These included aspiration biopsies of the lung various lymph nodes skin nodules etc Lymph nodes were the most commonly obtained specimen Divided in a manner similar to the bronchial biopsies there were 18 with no cancer diagnosis and 77 diagnoses of cancer As would be expected the number of inoperable cases was overwhelming particularly in those with positive biopsies (Table III)

PRESENTATION OF DATA

In trying to answer in part the questions asked in the second paragraph we have made various correlations between the histologic clinical and cytologic aspects of our cases The information derived will be developed in future sections of this paper Some of the information seems valueless, whereas other observations serve to define the value and limitations of exfoliative cytology in pulmonary cancer

Comparing the total number of bronchial washings and sputum examinations, it was noted that the percentage differences were not great. Among the 364 bronchial washings there were 59.3 per cent negative, 9.1 per cent suspicious, and 31.6 per cent positive examinations. The 905 sputa yielded 62.5 per cent negative, 10.4 per cent suspicious, and 27.1 per cent positive examinations. These figures give a slight advantage to bronchial washings in the way of a diagnosis of positive. Others[6, 16, 19, 32] have found the reverse to be true in their cases. Two observers[12, 13] found bronchial washings to be more reliable than sputum examinations. The obvious advantage of sputum for cell study is its availability and its repeated availability. This is particularly important considering the discomfort and apprehension associated with one and, more than one, bronchoscopic examination. Because of this and other factors an optimum number of specimens for a satisfactory examination has been cited by numerous observers. The figures usually range from 3 to 5. Philps[26] implies that five examinations would be optimum. In his 30 cases diagnosed cytologically, all of the diagnoses were made with five and less sputum specimens. Of 121 cases, Hjelt[14] diagnosed 112 with just two sputum samples. It seems that the optimum number of specimens varies a great deal. Our cases have been divided into three groups: less than three specimens, three specimens, and more than three specimens. These include sputa and bronchial secretions. It is noted that with three, and more than three studies, there is a distinct increase in the percentage of positive cases when compared to those with less than three examinations (Table V). This is particularly striking when there is no bronchial biopsy or a negative bronchial biopsy. In the presence of a positive bronchial biopsy the percentage difference of the groups is not great. The advantage of at least three cytologic examinations per case is evident. Our cases are most numerous in the first group (less than three specimens).

TABLE V. NUMBER OF SPECIMENS AND CYTOLOGY

	NO BRONCHIAL BIOPSY			NEGATIVE BRONCHIAL BIOPSY			POSITIVE BRONCHIAL BIOPSY		
	CASES AND PER CENT			CASES AND PER CENT			CASES AND PER CENT		
	NEGATIVE	SUSPICIOUS	POSITIVE	NEGATIVE	SUSPICIOUS	POSITIVE	NEGATIVE	SUSPICIOUS	POSITIVE
Less than 3 specimens/case	71 61.5%	5 4.4%	39 33.9%	16 39.0%	9 22.0%	16 39.0%	39 34.8%	12 10.7%	61 54.5%
3 specimens/case	23 44.2%	5 9.7%	24 46.1%	5 23.8%	6 28.6%	10 47.6%	16 27.0%	3 5.3%	40 67.7%
More than 3 specimens/case	17 39.5%	4 9.3%	22 51.2%	8 33.3%	3 12.5%	13 54.2%	10 29.4%	6 17.7%	18 52.9%

Note. The percentage is calculated for each separate category. The diagnoses changed in the review for this study are not included in this table.

SITE AND SIZE OF THE LESION

The relationship between the cytology and the lung involved showed no startling differences except in bronchial washings from the right lung, in which 77, or 34.6 per cent were positive. From the left lung there were 138 bronchial washings with 38 (27.5 per cent) positive. As to sputum studies, 362 specimens were from patients with cancer of the left lung and 535 from patients with cancer of the right lung. There were 103 (28.7 per cent) positive from the left lung and 139 (26.0 per cent) from the right lung. These figures were derived from 498 cases, as the location of the lesion could not be accurately determined in three cases. In an effort to determine which lobe yields the most and the least number of positive examinations we used all means available operative, autopsy, bronchoscopy, and x-ray reports to locate the lesion as to lobe involved. Main bronchus neoplasms and hilar lesions were assigned to the upper lobes. Among our 498 cases, we had 168 right upper lobe, 136 left upper lobe, 18 right middle lobe, 95 right lower lobe and 59 left lower lobe lesions. The remaining 22 were multiple lesions and could not be assigned to a specific lobe. The distribution of lesions by lobes compares closely to that in the large series of lung cancers reported by Aufses.[2] Cytologic examinations broken down by lobes showed the following interesting observations. Except for the left upper and right middle lobes, the bronchial washings yielded a significantly higher percentage of positive results. For example in the left lower lobe there were 26 (21.8 per cent) positive sputa as against 15 (40.5 per cent) positive bronchial washings. In the two excepted lobes the positive sputa exceeded positive bronchial washings. The left upper lobe gave the highest percentage of positive sputa (31.6 per cent) and the left lower lobe the lowest (21.8 per cent). The right lower lobe contributed the highest percentage of positive bronchial washings (40.8 per cent) and the left upper the lowest (23.4 per cent). In other *words* the *two upper* lobes produced the highest percentage of positive sputa and the lower lobes the highest percentage of positive bronchial washings. Perhaps the better drainage of the upper lobes explains the success of sputa in these lobes. The more suitable anatomy of the lower lobes for aspiration possibly accounts for the greater number of positive bronchial washings from these lobes.

To pin point further the relationship between cytologic studies and location of the lesions the specific site was determined as accurately as possible. Only pneumonectomies, lobectomies or autopsied cases were used. In many instances descriptions were vague which probably accounts for our small number of main bronchus lesions. Two hundred twenty-six cases were included in this portion of the study. As had been stated bronchial washings yielded a slightly higher or nearly equivalent, percentage of positive diagnoses than did sputa. This is true with one exception. This exception is in single and multiple peripheral lesions without demonstrable connection with bronchi. In thirteen peripheral lesions of the right lung there were no positive bronchial washings and 20.8 per cent positive sputa studies. The fourteen peripheral lesions of the left lung showed 2 (28.6 per cent) positive bronchial washings and 4 (13.3 per cent) positive sputa. The number of examinations in each of the lungs is few. However, it is gratifying to note that lesions of segmental bronchi and of peripheral areas do yield a respectable percentage of positive cytologic diagnoses (Table VI). Other writers[19-27] have demonstrated success in detecting peripheral lesions by cytologic means. Their number of cases is small. Farber and associates examined sputa and bronchial

TABLE VI. CYTOLOGY AND SPECIFIC SITE OF LESION

SPECIFIC SITE OF LESION	CASES	NUMBER OF SPUTA SPECIMENS			NUMBER OF BRONCHIAL WASHINGS		
		NEGATIVE	SUSPICIOUS	POSITIVE	NEGATIVE	SUSPICIOUS	POSITIVE
Left main bronchus	7	9 56.2%	0	7 47.8%	0	0	4 100%
Left major bronchi	30	32 57.0%	5 9.1%	19 33.9%	8 50.0%	0	8 50.0%
Left segmental bronchi	57	61 62.1%	8 9.3%	29 28.6%	26 65.0%	3 7.5%	11 27.5%
Left peripheral lesions	14	23 76.6%	3 10.1%	4 13.3%	5 71.4%	0	2 28.6%
Right main bronchus	3	0	3 42.8%	4 57.2%	2 50.0%	0	2 50.0%
Right major bronchi	49	86 75.4%	6 5.4%	21 19.2%	20 58.8%	2 5.9%	12 35.3%
Right segmental bronchi	53	57 60.6%	6 6.5%	31 32.9%	22 57.8%	3 8.0%	13 34.2%
Right peripheral lesions	13	18 75.0%	1 4.2%	5 20.8%	13 86.6%	2 13.4%	0

Note. The percentage was computed from the number of specimens for each separate category and separately for sputum and bronchial washings.

washings from 60 peripheral lesions. There were 4 positive bronchial washings and 32 positive sputa. Jennings and Shaw[17] reported 42 peripheral tumors of which 27 (64.3 per cent) had positive sputa. The success of the procedure as an aid in the diagnosis of peripheral and segmental lesions is evident.

The cytologic studies as related to the size of the lesion proved to be interesting. The size was measured in 191 of our cases. Lesions measuring up to 2 cm. in diameter, those from 4 to 7 cm. in diameter, and multiple lesions yielded fairly low percentages of positive cytologic studies. The percentage of positives ranged between 10 and 25 per cent. Those lesions which measured 2 to 3 cm. and over 7 cm. showed a definite percentage increase of positive studies. In the 2 to 3 cm. group there were 31.5 per cent positive sputa and 30.7 per cent positive bronchial washings. In the lesions over 7 cm., 35.8 per cent had positive sputa and 37.5 per cent had positive bronchial washings. It appears that small lesions (2 cm. and less), middle-sized lesions, and multiple lesions do not readily give up their neoplastic cells. In their analysis of factors responsible for cytologic failures, Bufimire and McDonald[4] did not mention the size of the lesion. The significance of these findings is not readily apparent. We suspect that they mean nothing. However, it is possible to state that small lesions, less than 2 cm., do yield neoplastic cells even though the percentage is small. Thus, the examination may be said to be of some aid in defining the nature of small pulmonary lesions. Experiments by Appel and Bronk[1] support these observations. They transplanted tumor to bronchi of rabbits and made frequent periodic smears of the bronchi. In seventeen (58 per cent) of their animals tumor was recognized in the smear before it was evident grossly or by x-ray.

From our resections and autopsies, 134 cases were found to have positive regional lymph nodes. Ninety-four cases had negative nodes. With positive nodes, bronchial washings yielded 35 (36.8 per cent) positive smears and with negative nodes 16 (24.6 per cent) positive smears. The percentage of positive sputa was nearly equal: 68 (27.0 per cent) with positive nodes, and 54 (30.3 per cent) with negative nodes. This is an observation the significance of which is not apparent.

Cytologic examinations in the 163 pneumonectomy cases totaled 307 sputa and 120 bronchial washings. Divided among the lobes, the bronchial washings were generally more rewarding in percentage of positive results than were sputa. The one exception was again noted to be in the left upper lobe. The right lower and left upper lobes showed the highest percentage of positive sputa, 33.3 per cent and 31.6 per cent, respectively. The lower lobes gave the highest percentage of positive bronchial washings, 39.1 per cent from the right lobe and 58.8 per cent from the left lobe. Thirty-five lobectomy cases produced 67 sputa and 26 bronchial washings. The numbers are few but show that sputa were more frequently positive in cases of cancer of the right lung. The number of positive bronchial washings and sputa was nearly equal in left lung lesions. In the 126 cases in which only an exploratory thoracotomy was done 236 sputa and 92 bronchial washings were obtained. Bronchial washings showed a higher percentage of positive results in each lobe except the left upper, where there were 26 per cent positive sputa and 12.5 per cent positive bronchial washings. The cytologic examinations from the autopsied cases were so few as to make the results meaningless. The results, especially from the pneumonectomies, were similar to those in a preceding paragraph. Lobectomy and explored cases deviated slightly. We are unable to add any further explanation for these observations other than that mentioned.

Our number and grouping of bronchial biopsies have been mentioned on preceding pages. Cytologic studies associated with bronchial biopsies were interesting but fall into an expected pattern. There was a high percentage of positive bronchial washings (42.9 per cent) with positive bronchial biopsies. This result could well be altered by the technique of washing, that is, the vigor of the washing or whether it was done before or after the biopsy. If done after, it is conceivable that dislodged tumor cells may help make the cytologic examination successful. On the other hand, blood may obscure or dilute tumor cells so as to make their detection more difficult. Herbut[10] feels the amount of saline used is important; the return should be sticky. He found that with watery washings the results are uniformly poor. With a positive bronchial biopsy, sputa were positive 29.5 per cent of the time in our cases. With a negative bronchial biopsy or no bronchial biopsy, the percentage of positive sputa and bronchial washings was similar, ranging between 22.6 per cent and 26.1 per cent (Table VII). Thus it would appear that as a pulmonary cancer becomes available to the biopsy forceps the number of positive smears increases notably, as would be expected. This is particularly true of bronchial washings.

With regard to operability and inoperability the following observations were made. One hundred ninety-eight (39.5 per cent) cases were counted as

TABLE VII CYTOLOGY AND BRONCHIAL BIOPSY

	SPECIMENS	PER CENT OF TOTAL	NO BRONCHIAL BIOPSY		NEGATIVE BRONCHIAL BIOPSY		POSITIVE BRONCHIAL BIOPSY	
			CASES	SPECIMENS	CASES	SPECIMENS	CASES	SPECIMENS
Negative BW*	216	(59.3%)	98	103 (70.0%)	40	43 (62.3%)	62	70 (46.9%)
Suspicious BW	33	(9.1%)	10	10 (7.4%)	8	8 (11.6%)	15	15 (10.2%)
Positive BW	115	(31.6%)	33	33 (22.6%)	18	18 (26.1%)	62	64 (42.9%)
No BW	158			72		19		67
Negative sputa	566	(62.5%)	128	250 (67.4%)	55	99 (63.0%)	114	217 (57.5%)
Suspicious sputa	94	(10.4%)	22	26 (7.0%)	19	21 (13.5%)	44	47 (13.0%)
Positive sputa	245	(27.1%)	68	95 (25.6%)	26	37 (23.5%)	83	113 (29.5%)
No sputa	77			37		12		28

*BW = Bronchial washing

operable and 303 as inoperable. Gibbon[9] had 39 per cent resectable cases out of 484 pulmonary cancers, and Aufses[2] reported 17 per cent in over 900 pulmonary cancers. A small number of lobectomies and segmental resections were done for metastatic lesions in our series. In our group 110 (56.1 per cent) operable cases had positive cytology. Of the inoperable cases 179 (59.0 per cent) had positive cytologic examinations. With a positive biopsy as an added factor the results were very different. In our 252 cases in this group 71.5 per cent were inoperable, and 22.3 per cent operable. These patients had a positive biopsy and a negative, suspicious, or positive cytology. When a negative biopsy was obtained or no biopsy taken, the percentage of operable cases is notably better. A positive cytology in the latter two groups does not influence the operability (Table VIII). It would appear from these observations that a positive cytologic examination does not influence the chance that a given case or group of cases will be operable or inoperable to the extent that a positive biopsy does. A positive biopsy, as far as our figures are concerned, means there is a 3 to 1 chance the case is inoperable.

The biopsies in the operable cases were all bronchial except six. Only one of the six was positive, an aspiration biopsy of the lung. Cytology is of no help to the clinician in the group of operable cases with positive biopsies,

TABLE VIII OPERABLE AND INOPERABLE CASES

CYTOLOGY	BIOPSY	OPERABLE		INOPERABLE	
		CASES	PER CENT	CASES	PER CENT
Positive	Positive	39	14.5	123	45.8
Suspicious	Positive	0		2	0.7
Negative	Positive	21	7.8	67	25.0
Total		60	22.3	192	71.5
Positive	Negative	27	35.5	21	27.6
Suspicious	Negative	1	1.4	2	2.8
Negative	Negative	13	17.1	12	15.6
Total		41	54.0	35	46.0
Positive	No biopsy	43	27.3	30	19.1
Suspicious	No biopsy	3	1.8	1	0.6
Negative	No biopsy	39	24.8	32	20.4
Total		85	53.9	63	40.1

Note. In the total of operable and inoperable cases, there are 12 palliative resections (for metastases) and 13 cases who refused operation or were considered poor risks. Their totals were used in computing the percentages but are not shown on the chart.

it is only interesting. The cases in which the cytology is of greatest help are in those patients with positive cytology and either a negative or no bronchial biopsy. Fifty-nine cases fall into this group. These cases do not include those changed from negative or suspicious to positive when this study was undertaken (Table IX). In these cases, the cytology represented the sole positive tissue diagnosis prior to operation. The degree of trust placed in the cytologic diagnosis was indicated by the small number of frozen sections asked for by the thoracic surgeons. But 13 frozen sections were requested to confirm the diagnosis in our 59 cases. We feel that with a positive cytologic diagnosis the surgeon should go ahead with the resection without use of frozen section. By doing so, tumor tissue is not incised and thereby exposed to the pleura and other tissues. The possibility of implantation of cancer cells is minimized.

TABLE IX. CYTOLOGY AND BIOPSY IN OPERABLE CASES

	POSITIVE CYTOLOGY	NEGATIVE OR SUSPICIOUS CYTOLOGY
Positive bronchial biopsy	35 (17.7%)	25 (12.6%)
Negative bronchial biopsy	18 (9.1%)	20 (10.1%)
No bronchial biopsy	41 (20.3%)	59 (30.2%)

Note. The percentages are computed for the entire group. The cytology is reported as a case.

Thus, of the operable cases 29.8 per cent fell into the group in which a definitive diagnosis of cancer was made by the cytologic smear. Many other writers have had similar cases in their series. Watson and associates[30] reported 7 of 26 pulmonary resections, and Jennings and Shaw[17] 64, done on the basis of cytology alone. Woolner and McDonald[32] had 23 such patients in their group. Wandall's[29] 100 cases included 12 operated on with only a positive cytologic diagnosis. Of our 59 cases, 48 were resections with the cytology as the only positive preoperative tissue diagnosis, as only 13 frozen sections were requested, and 2 of these were reported as showing chronic inflammation. Resection was done in these two cases. It is in this group of patients that cytology is most helpful and represents the area in which every effort should be made to improve the accuracy of diagnosis.

TYPING OF SMEARS

A facet of pulmonary exfoliative cytology recently explored by Foot[8] is an interesting one, namely, the study of cytologic typing of the positive smears. In his review of 341 cases the over all accuracy of typing is 80 per cent. The accuracy varied with the histologic type. His epidermoid carcinomas were accurately typed in 89.9 per cent of instances, whereas pleomorphic carcinomas were diagnosed in 69.2 per cent of the cases. Of 2 bronchial adenomas and 5 alveolar cell carcinomas, none was correctly typed from the smears. Umiker[27] mentions that in his 14 cases with positive cytology a correct histologic typing was made in eleven. He states further, that in every instance epidermoid carcinoma and pleomorphic carcinoma were recognized.

In this study, cancer of the lung has been divided into seven groups epidermoid carcinoma, undifferentiated carcinoma, adenocarcinoma, adenocarcinoma grade I (so-called bronchial adenoma), bronchiolar carcinoma, metastatic carcinoma, and others The large-cell and small-cell carcinomas are included in our undifferentiated carcinomas Included in our "other" tumors is one lymphosarcoma, a carcinosarcoma, and neoplasms which we were unable to classify With these as our histologic groups we attempted to determine the types of our 290 cases with positive smears

No appreciable difference in determining the histologic type was encountered between sputa and bronchial smears Our criteria for typing the smear were similar to those of Foot and the Vincent Memorial Hospital group[28] Because of the difficulty in distinguishing poorly differentiated epidermoid carcinomas and undifferentiated carcinomas, even histologically, a slight modification was made in our tabulations If a cancer were found to be a poorly differentiated epidermoid carcinoma, histologically, and typed as undifferentiated, it was not counted as an error The reverse of this was not used in tabulation

Generally our typing (Table X) was as successful as Foot's and that of Memorial Hospital group used by Foot for comparison We have an over-all accuracy of 79 3 per cent as determined from 230 correct and 60 incorrect One case was not typed because of loss of the slides, but was counted as incorrect

TABLE X RESULTS OF CYTOLOGIC TYPING

HISTOLOGIC TYPE	CYTOLOGIC TYPE AS DETERMINED FROM THE SMEAR (CASES)					
	EPIDERMOID CARCINOMA	UNDIFFERENTIATED CARCINOMA	ADENOCARCINOMA	ALVEOLAR CELL CARCINOMA	NEGATIVE AND SUSPICIOUS CYTOLOGY	TYPING ACCURACY
1 Well differentiated epidermoid carcinoma	97	11	2	0	30	89 2%
2 *Poorly differentiated epidermoid carcinoma*	*37*	21	*7*	0	54	
3 Undifferentiated carcinoma	13	48	2	0	80	76 2%
4 Adenocarcinoma (includes metastatic adenocarcinoma)	4	1[illegible]	11	0	32	39 3%
5 Bronchial adenoma	1	1	1	0	8	33 3%
6 Bronchiolar carcinoma	0	0	0	2	2	100%
7 Others	1	3	0	0	5	0 0%
8 Metastatic carcinoma (except adenocarcinoma)	3	0	0	0	2	100%

Note Over all typing accuracy was 79 3 per cent

One hundred eighty-five cases of epidermoid carcinoma had positive smears One hundred sixty-five were correctly typed for a percentage of 89 2 per cent This compares with New York Hospital's 87 7 per cent Our errors in this group were greatest in calling well differentiated epidermoid carcinoma, undifferentiated Nine were typed as adenocarcinoma The undifferentiated carcinomas were typed accurately in 76 2 per cent of cases Adenocarcinomas were typed correctly in 39 3 per cent of the cases Included in adenocarcinomas are the bronchial adenomas and metastatic adenocarcinomas Nine of our cases of metastatic carcinoma had positive cytologic examinations Most of the errors were in typing adenocarcinomas as epidermoid carcinomas We were unable to differentiate primary and metastatic adenocarcinomas Three metastatic epidermoid carcinomas were typed correctly Of our 11 bronchial adenomas 3 had positive smears One was typed as undifferentiated carcinoma one epidermoid and one adenocarcinoma The latter was considered correct because of our feeling that bronchial adenomas are adenocarcinomas grade I To illustrate further the difficulty of typing bronchial adenomas Foot typed 2 in his series as anaplastic carcinomas Two bronchiolar carcinomas of 4 in our group had positive smears Both were typed correctly

We feel that most of our errors may be explained by the vagaries of pulmonary cancers as far as their histology is concerned Several of our cases show a combination of structure e g epidermoid carcinoma with areas of adenocarcinoma A few of the epidermoid carcinomas had areas which could readily be mistaken for a renal-cell carcinoma Undifferentiated or poorly differentiated epidermoid carcinomas with large vacuolated cells could be confused with adenocarcinomas as far as the smear is concerned. It is difficult to explain the poor showing with adenocarcinomas Several histologically were composed of cells with dense acidophilic, rather than vacuolated cytoplasm or were not well differentiated (Figs 1 through 8)

Typing of smears may give the surgeon valuable preoperative information The difference in prognosis between epidermoid and undifferentiated carcinoma is well known This information and the implications as to resectability may be provided by the smear Support for this is given by Borrie[3] In a review of 200 resected pulmonary cancers he observed that 42 5 per cent of epidermoid carcinomas and 70 per cent of undifferentiated carcinomas had lymph node metastases In cases of bronchiolar carcinoma typing of smears gives information important to surgical treatment of the disease It may aid in the decision as to lobectomy or pneumonectomy To support this Kirklin and McDonald[18] reported finding malignant cells in the sputa and bronchial washings of 9 out of 14 alveolar-cell tumors of the lung Only one was diagnosed by biopsy Typing of smears may well have its place on the report to the clinician

DURATION OF SYMPTOMS

As a last bit of information which came to light in our study we have the relationship between the duration of symptoms and the cytologic examinations To date the duration of symptoms we used the first complaint which seemed related to the illness that was made by the patient We realize that the date of onset will vary with the manner in which and the persistence with which questions are asked of the patient With that in mind we have made the following observations There were two peaks for bronchial washings and one for sputa, i e peaks for a high percentage of positive smears The first for bronchial washings came at 3 months The second which is also the peak for sputa came in the 6 to 11 months period In this latter time period the sputa were positive in 34 7 per cent of examinations and bronchial washings in 36 0 per cent Except for the peaks mentioned the percentage of

Fig 1

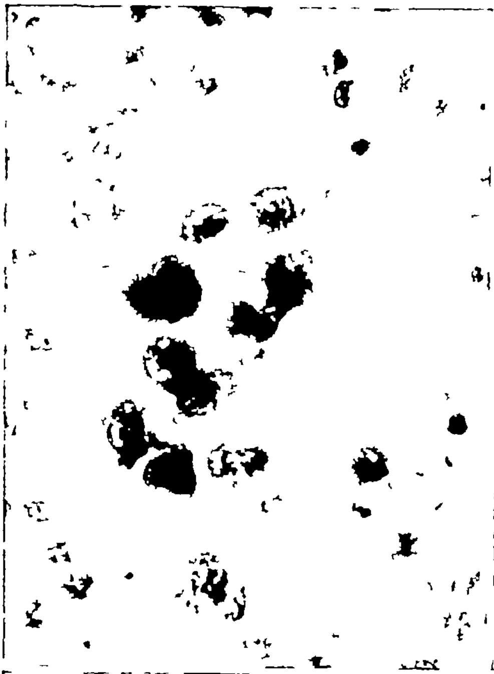
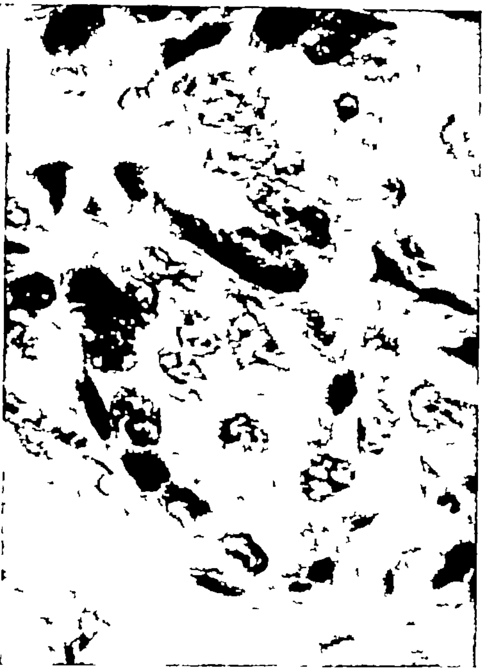


Fig 2



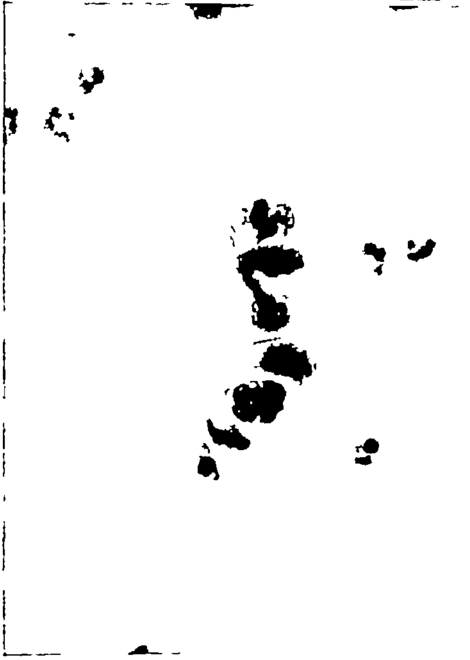


Fig 3

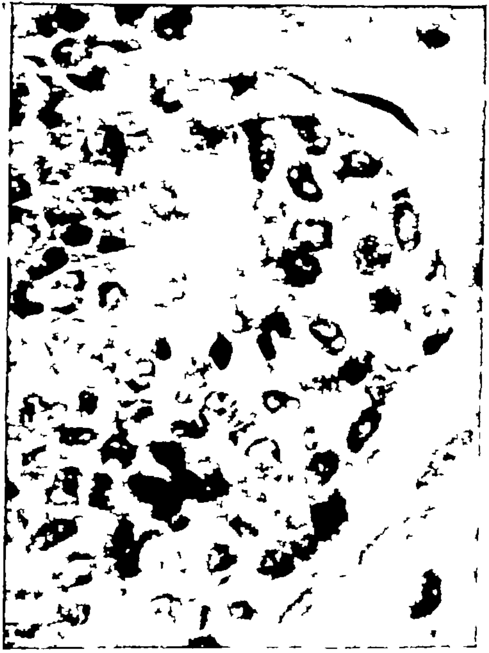


Fig 4

Fig 1.—Sputum was cytologically typed as adenocarcinoma because of vacuolation and was found to be histologically undifferentiated carcinoma (×600)

Fig 2.—Tissue section is illustrative of an area in which the cells are similar to those in the sputum (×600)

Fig 3.—Sputum was cytologically typed as adenocarcinoma because of apparent cytoplasmic vacuolation and was found to be histologically epidermoid carcinoma (×600)

Fig 4.—Demonstrates an area of vacuolated cells in the tissue section which if exfoliated could be confused with adenocarcinoma (×600)

The illustrations of the tissue sections were taken at the same magnification as the smears to show cell detail and not histologic pattern in the case of the tissues

Fig 5

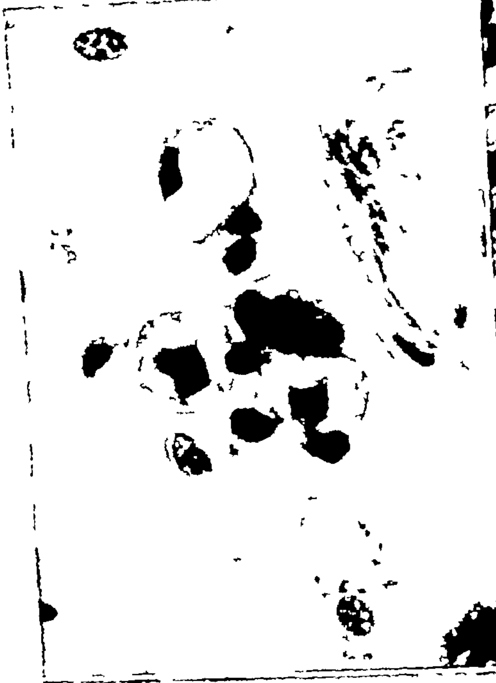


Fig 6

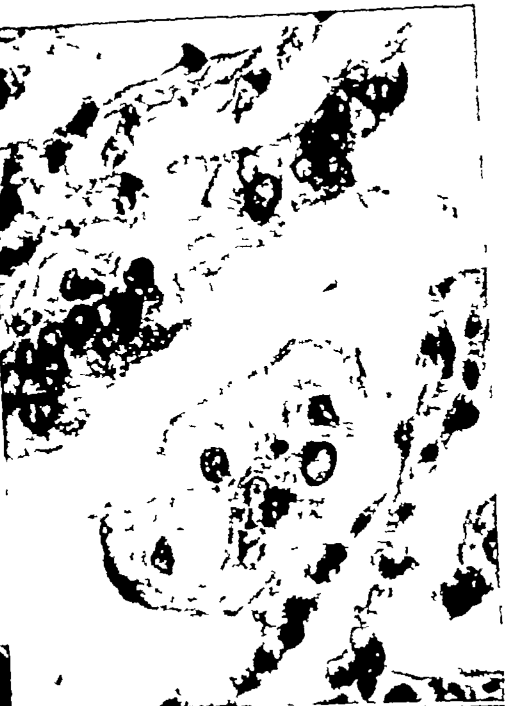


Fig 7

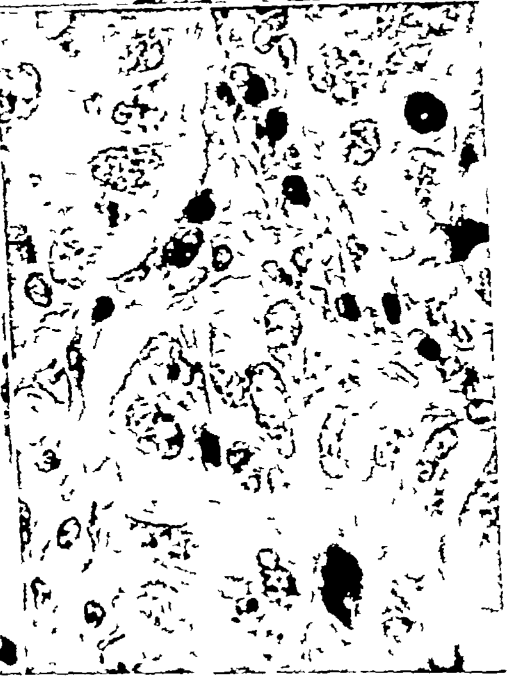


Fig 8

Fig —Demonstrates an alveolar-cell carcinoma which was accurately typed cytologically (×600)

Fig 6—From a tissue section illustrating the similarity of the cells to those in Fig 5 (×600)

Figs 7 and 8—These two sections are sputum and tissue, respectively This is an accurately typed adenocarcinoma primary in the lung (×600)

The illustrations of the tissue sections were taken at the same magnification as the smears to show cell detail and not histologic pattern in the case of the tissues positive smears remains level in both sputa and bronchial washings The most notable dip is to 20 7 per cent positive sputum examinations when the symptoms were present for one year or longer From these observations, it might be stated that with manifest symptoms of short duration, up to 3 months, cytologic examinations are a distinct aid in diagnosis Why there should be a difference in yield of positive examinations at different time periods we cannot say

DISCUSSION

Our over-all success in positive cytologic diagnosis is 57 8 per cent This is without correction for the so-called optimum number of examinations If this correction is made, the number of cases with positive smears may potentially be as high as 85 to 90 per cent[7, 16, 25] Our percentage for the optimum number of examinations is 76 6 per cent The percentage was derived by eliminating cases with less than three cytologic examinations This figure or even those without correction, plus the fact that the number of false-positive examinations is almost at an irreducible minimum, serves to emphasize the value and reliability of cytology as an indispensable aid in the workup of patients suspected of pulmonary cancer Recently McDonald[21] stated that in 1,500 positive reports at the Mayo Clinic there were 24 false positive reports, or 1 6 per cent At Barnes Hospital, as previously stated, there have been no false positive reports during the past three years Although the percentage of false positives is low the fact remains that it is the case which is important Even one or two false-positives are too many when a needless pneumonectomy may have resulted because of the erroneous cytologic report As a further step, it is suggested that cytologic examinations be used in the follow up of patients with pulmonary resection This would be of particular importance in bronchiolar carcinomas, with their known multiple foci This phase of cytology has not been extensively explored by us, although cases of cancer persistent at the bronchial stump have been detected One case of recurrent bronchiolar carcinoma has been diagnosed by follow up cytology

Bronchial washings throughout our study, with certain exceptions, were consistently more productive of positive results than were sputa More than twice as many sputa were examined This may account for the slightly lower percentage of positive smears But the large numbers of both should be a point against the bronchial washings being superior to sputum examinations only on the basis of numbers The consistency with which bronchial washings remain superior to sputum examinations when correlated with the site of the lesion, size, and duration would make it appear that for this series at least the observation seems valid Both have their advantages, however Sputum is readily available, repeatedly available and inexpensive to procure Bronchial washings have the advantage of being a more selective specimen as far as location of the lesion in the lung is concerned They eliminate desquamated cells from other parts of the respiratory tract and mouth In addition, bronchial washings are important in cases presenting with a nonproductive cough

From the outset it was the purpose of this study to define the limitations of cytology in pulmonary cancer and perhaps to increase the information gained therefrom. Cytology is obviously of little value in the localization of a cancer in the respiratory system. In our review in regard to this point the right lung lesion gave a higher percentage of positive results than did the left. This was true of bronchial washings and sputum examinations. Both lower lobes yielded a fairly high percentage of positive bronchial washings compared to the other lobes. The sputa, on the other hand, were reasonably evenly distributed among the lobes. In our experience cytologic findings are of no aid in localizing a lesion to a specific portion of a lobe. The only pertinent observation to be made is that the peripheral lesions arising in bronchioles give a low percentage of positive sputa and bronchial washings.

The size of the lesion, when correlated to the cytologic findings, showed the large tumors (above 7 cm.) and tumors 2 to 3 cm. give a significantly higher percentage of positive reports than did other lesions. With large lesions, this may be explained on erosion into multiple bronchi and bronchioles, thus greatly increasing the surface of tumor from which cells exfoliate. On the other hand, many large tumors display extensive necrosis. With large amounts of necrotic material in the secretions, results were supposedly poorer.[16] We have no explanation for the results obtained in the small neoplasms.

With erosion of the tumor or invasion of a bronchial wall as seen grossly or microscopically more positive results occurred. In our 172 cases in which erosion or invasion was demonstrated 95 (29.5 per cent) of the sputa and 45 (36.3 per cent) of the bronchial washings were positive. Without erosion or invasion (56 cases) there were 27 (24.3 per cent) positive sputa and 6 (15.0 per cent) positive bronchial washings. These results are what one would expect. The number of tumors with erosion or invasion could undoubtedly be altered by taking more than the three sections of the tumor as we routinely do in our laboratory. Positive regional lymph nodes are associated with a higher percentage of positive cytologic (bronchial washings) results. The large majority of the nodes were dissected from surgically resected specimens. This latter finding suggested, even though weakly, that a positive bronchial washing may be a sign of poor prognosis. Interestingly enough, the duration of symptoms caused no great variation in the cytologic results. Notable is the low percentage of positive sputa in cases with symptoms of long duration. This may be a reflection of the slow progression of the tumor or that the lesion is more peripheral. Even with symptoms of short time span, a significant number of positive sputa and bronchial washings were obtained. This observation serves to emphasize the value of a cytologic examination in the face of unexplained respiratory symptoms even of short duration.

A comparison of operability versus inoperability is detailed in the body of this paper. Comparing lobectomies and pneumonectomies to cases only explored we found the percentage of positive sputa and bronchial washings to be much the same in the two groups. This was not computed on a case basis. The findings are similar to those reported by Wandall.[20] Jennings and Shaw[13] feel that malignant cells in the sputum are found with equal frequency in operable or advanced cases. Iversen[12] had 47 per cent positive cytology in inoperable cases as against 42 per cent in resectable cases From our study it would seem that a positive biopsy in a given case means a greatly lessened chance for operability A positive or negative cytology report does not seem to alter the chance of operability greatly This is borne out by the number of cases with negative sputum and either a negative biopsy or no biopsy In the operable group there were 52 such cases and 44 in the inoperable It appears that cytology in pulmonary cancer is of little or no prognostic value

SUMMARY

1 Five hundred and one histologically confirmed cases of pulmonary cancer and their cytology were reviewed

2 For tissue confirmation there were 318 bronchial biopsies, 95 other biopsies, 163 pneumonectomies, 35 lobectomies, 126 exploratory thoracotomies, and 35 autopsies

3 Twelve hundred sixty-nine cytologic smears were studied, including 905 sputa and 364 bronchial washings

4 Thirty-one and six-tenths per cent of the bronchial washings were positive, and 27 1 per cent of the sputa were positive

5 On a case basis the over-all percentage of positive reports was 57 8 per cent and with an optimum number (3 or more) specimens, 76 6 per cent

6 The optimum number of sputa and bronchial washings for study was found to be three

7 Of the 318 bronchial biopsies 211 or 66 3 per cent were positive Only 28 per cent of the positive biopsies were in the operable cases

8 The lower lobes yielded the highest percentage of positive smears (bronchial washings) The highest percentage of positive sputa was obtained from the left upper lobe

9 Cytologic examinations are of value in the diagnosis of peripheral pulmonary cancers

10 Lesions 2 to 3 cm in diameter and those larger than 7 cm produced the highest percentage of positive smears

11 Cases with positive hilar and bronchopulmonary nodes yielded a higher percentage of positive bronchial washings than did those with negative nodes Sputum examinations remained much the same for the two groups

12 Positive smears were obtained in 56 1 per cent of the operable cases and 59 per cent of the inoperable cases

13 With a positive biopsy, the number of operable cases decreases notably

14 In 59 of our operable cases, the cytology was the only positive tissue examination prior to operation Thirteen frozen sections (with eleven positive) were asked for in these cases Thus, 48 of our cases were resected with cytology as the sole tissue diagnosis

15 Typing of the positive smears was 79 3 per cent accurate Epidermoid carcinomas were correctly typed in 89 2 per cent of instances, undifferentiated carcinomas in 76 2 per cent, and adenocarcinomas in 39 3 per cent Two bronchiolar carcinomas were accurately typed from the smears

We wish to acknowledge the valuable assistance of Mrs Delores Wallen of the cytology laboratory

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THROMBOSIS OF THE PULMONARY ARTERY COMPLICATING A CASE OF PULMONARY TUBERCULOSIS

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STOCKHOLM, SWEDEN

IN CASES of pulmonary tuberculosis, the arterial branches close to the tuberculous lesions are sometimes found thrombosed Occasionally a segmental artery is found thrombosed, but only once in a series of 500 resections for pulmonary tuberculosis was the main pulmonary artery found almost completely occluded After excision of the thrombosed area of the pulmonary artery and a left upper lobectomy with decortication of the lower lobe, the oxygen uptake increased from 4 to 15 per cent on the left side, and an angiography showed a patent pulmonary artery

CASE REPORT

A 36 year old man developed a large tuberculous cavity in the left upper lobe in 1946 and was treated with an artificial pneumothorax There was a spread to the right side with a cavity in the superior segment of the right lower lobe in 1948 A good regression occurred on the right side On the left side, the pneumothorax was abandoned in 1953 with considerable displacement of the mediastinum to the left The cavity was still visible in the left upper lobe There was no bronchial stenosis Bronchospirometry showed 4 per cent oxygen uptake, 7 per cent of the vital capacity, and 2 per cent of the minute ventilation on the left side

A two stage procedure was performed in January, 1953, with a preliminary 5 rib thoracoplasty with apicolysis (Fig 1) Three months later, the left side of the chest was opened through the bed of the sixth rib The lung was mobilized in the extrapleural plane, and the lower lobe was decorticated The segmental arteries to the left upper lobe were dissected free, and divided The most proximal segmental artery to the anterior segment was thrombosed As the main pulmonary artery at this level was felt firm on palpation, it was dissected free centrally to the bifurcation and opened between clamps A 2 by 2 by 2 cm large thrombus was found adherent to the wall of the pulmonary artery around the orifice to the anterior segmental artery The opposite wall of the pulmonary artery was free The lumen was 90 per cent occluded The wall of the pulmonary artery containing the thrombus was excised and a continuous suture of silk was applied (Fig 2) The left upper lobe was removed and immediately after the operation, bronchospirometry showed 11 per cent oxygen uptake on the left side The preoperative value had been only 4 per cent

Microscopic examination revealed a normal wall of the pulmonary artery and an organized thrombus

The patient made an uneventful recovery One year after the operation, the patient showed a negative guinea pig test on sputum and gastric washings, and had an x ray of the chest (Fig 3) very similar to the preoperative one (Fig 1) Angiography showed a normal left pulmonary artery Bronchospirometry showed 15 per cent oxygen uptake, 16 per cent minute ventilation and 17 per cent vital capacity on the left side

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From the Sabbatsberg Hospital Surgeon in-chief C Crafoord M D Professor Physician in-chief S Björkman M D

Received for publication Jan. 8 1955

DISCUSSION

A slow rate of blood flow will increase the risk of thrombosis. In this case the left lung was atelectatic during one period of the pneumothorax treatment. The decreased blood flow through the left lung may then have facilitated the thrombus formation originating from a segmental artery. Before the operation, only 2 per cent of the minute ventilation was on the left side. Therefore a thrombosis of the left pulmonary artery was not expected

Fig. 1—X-ray of the chest in March 1953 before the operation

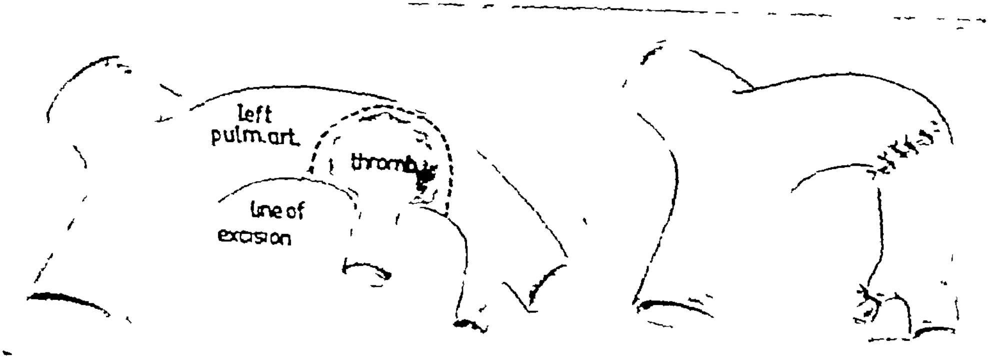

Fig. 2—Diagram of the thrombus in the left pulmonary artery, the excision and the vascular repair

preoperatively As ventilation increased after the operation from 2 to 16 per cent and the oxygen uptake from 4 to 15 per cent, the decortication played an important part in the improvement of function

Such an improvement would, however, never have been possible without the excision of the thrombus After the operation, there was no thrombosis in the suture line

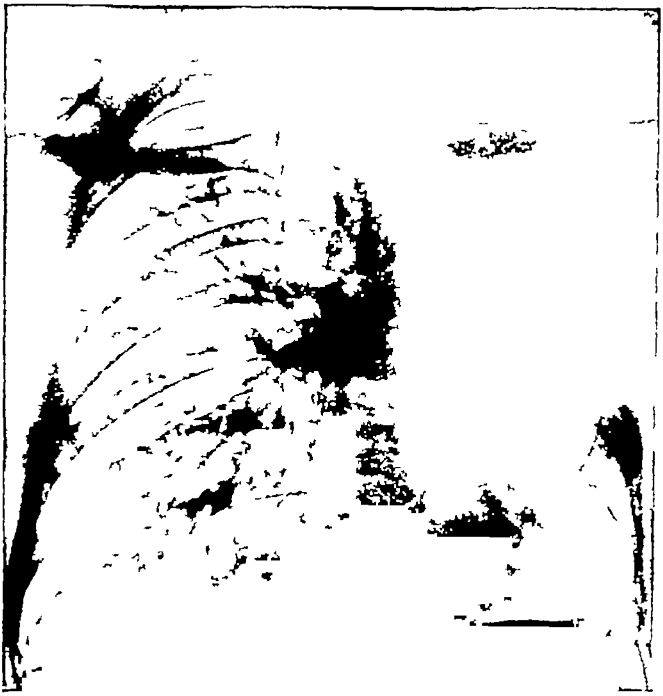

Fig 3 —X ray of the chest in March 1954 one year after the operation

In cases with practically no oxygen uptake in one lung, a thrombosis of the pulmonary artery may be detected by angiography At operation, the pulmonary artery may easily be palpated and, if something unusual is found, it should be opened as in the case described Excision of a thrombus, with the adjacent pulmonary arterial wall and a vascular repair, can evidently be done without recurrent thrombosis in spite of a comparatively small flow

SUMMARY

A case is described in which a left upper lobectomy, left lower lobe decortication, and excision of a thrombus formation in the left pulmonary artery improved the oxygen uptake from 4 to 11 per cent One year later the oxygen uptake was 15 per cent on the left side, and the left pulmonary artery was patent

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TECHNIQUE OF BRONCHOGRAPHY

S W French, III, Colonel, MC, USA
San Francisco, Calif

THE following line drawings illustrate the various positions which the author has successfully used for several years in bronchography This method is simple, can be performed quickly without the aid of fluorscopy, and uniformly produces excellent bronchograms

Topical 5 per cent cocaine anesthesia is used, the pharynx being sprayed with an atomizer, following which the internal division of the superior laryngeal nerve is cocainized in the anterior portion of the piriform sinus with a Jackson forceps containing cotton saturated with the anesthetic agent A catheter is then inserted through the nose into the trachea under direct vision by use of a laryngeal mirror Following insertion of the catheter, a total of 4 c c of cocaine is instilled into the trachea through the catheter, with the patient leaning first to the right and then to the left in order to complete the anesthesia of the tracheobronchial tree

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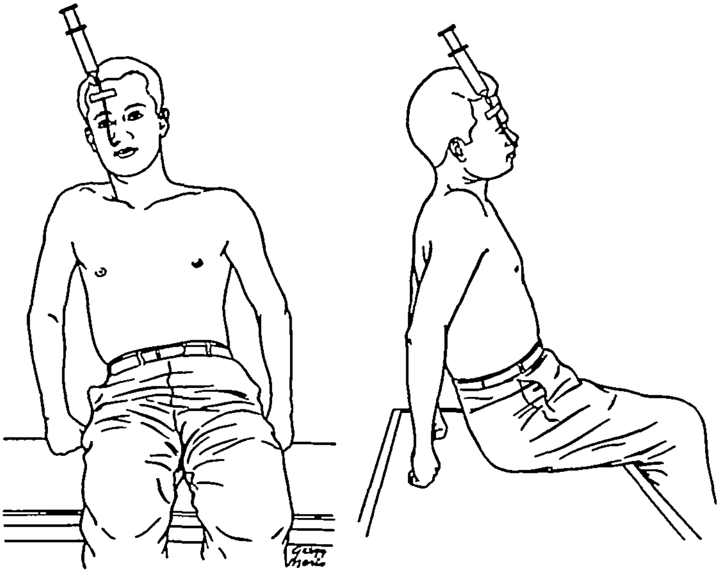
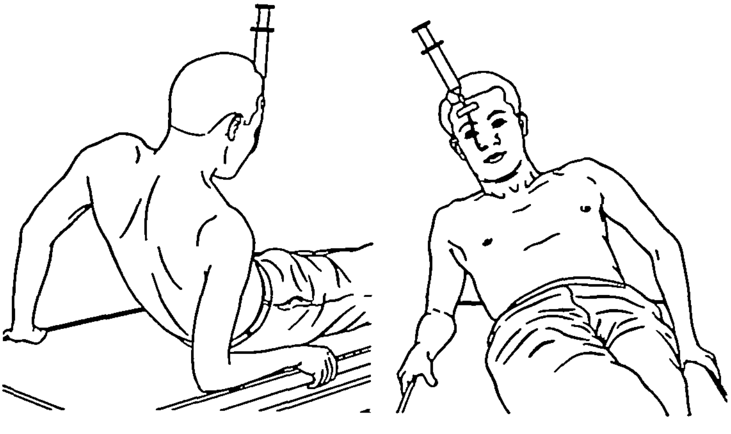
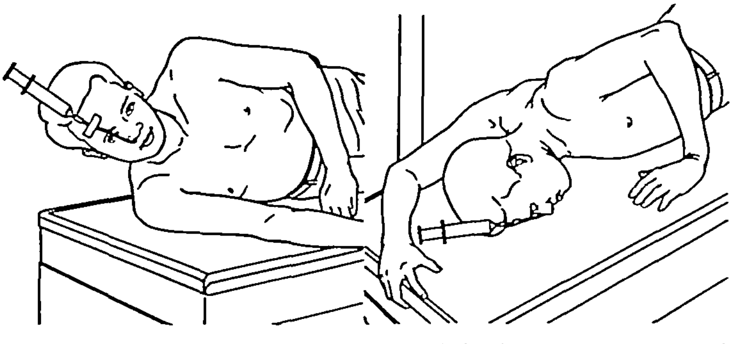
From the Thoracic Surgical Service Letterman Army Hospital San Francisco Calif
Received for publication Feb 3 1955



Position 1—Frontal and lateral views In this position instill 6 c c of Lipiodol wait 30 seconds and proceed to Position 2

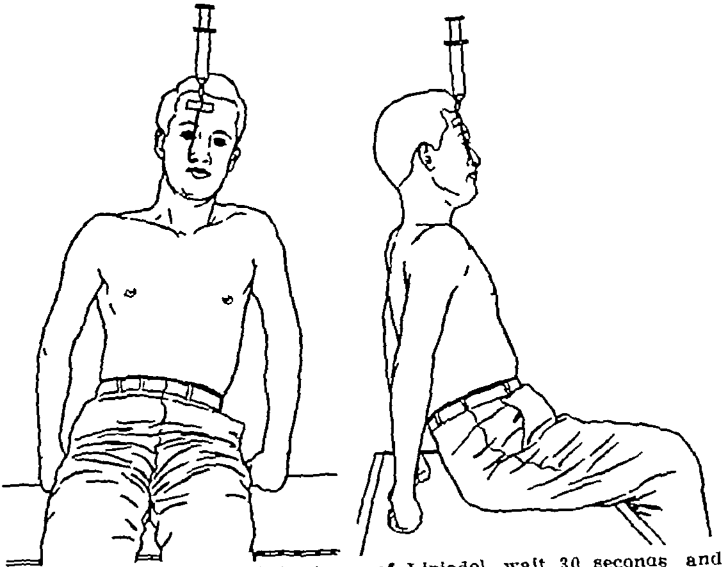


Position 3—Instill 3 c c of Lipiodol wait 30 seconds and proceed to Position 4

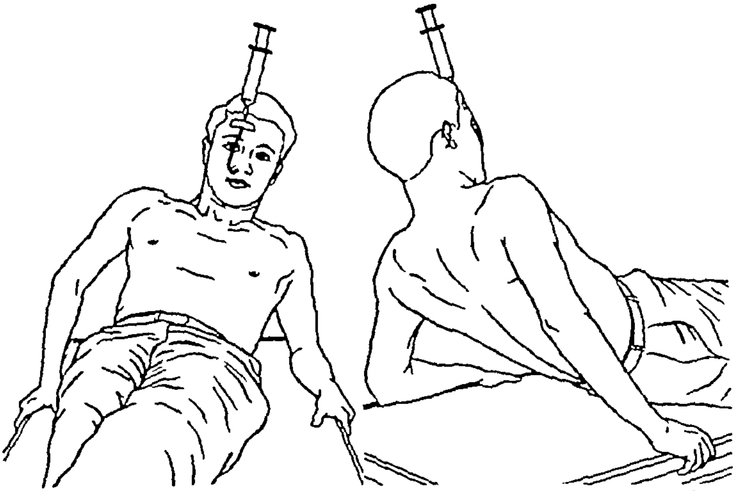


Position 5—With the patient in the right lateral decubitus position (above left) instill 3 c c *of Lipiodol and* wait 30 seconds The patient is then turned to the right anterior oblique position as in the figure above the table depressed to a 30 degree angle and held in this position for 30 seconds

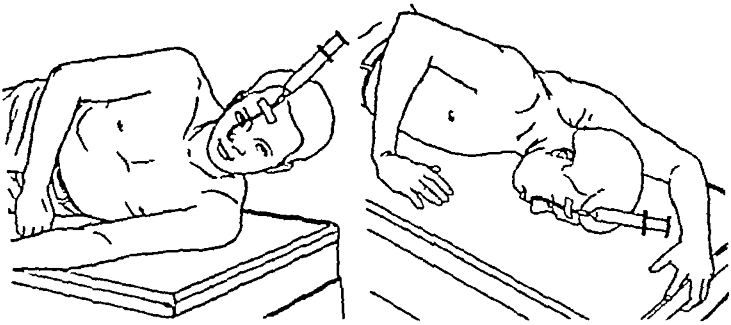
FRENCH TECHNIQUE OF BRONCHOGRAPHY



Position 2.—In this position instill 3 to 4 c.c. of Lipiodol, wait 30 seconds and proceed to Position 3



Position 4.—In this position instill 3 c.c. of Lipiodol, wait 30 seconds, proceed to Position 5



Position 5.—With the patient in the left lateral decubitus position (above left) instill 3 c.c. of Lipiodol and wait 30 seconds. The patient is then turned to the left anterior oblique position as in the figure above, the table depressed to a 30 degree angle and held in this position for 30 seconds.

At this time posteroanterior and right and left anterior oblique films are taken with the patient upright. Lateral films may be taken if so desired.

THE HISTORY OF THE DEVELOPMENT OF THE NEGATIVE DIFFERENTIAL PRESSURE CHAMBER FOR THORACIC SURGERY

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NEW YORK, N. Y.

IN 1953 at the San Francisco meeting of the American Association for Thoracic Surgery, Dr. Robert M. Janes, in his Presidential Address, spoke about the negative pressure chamber. He stated that the only one in existence in America in 1922 was located at the Lenox Hill Hospital in New York. Willy Meyer, who designed it, had combined the principles of negative pressure of Sauerbruch and the principles of positive pressure of Brauer.

It occurred to me at that meeting that some of the members and visitors might not have heard about the negative chamber, or understood what was meant by the term "negative pressure chamber." Therefore, I thought a brief historical sketch might be timely and possibly of interest for those whose interest in thoracic surgery followed the birth, life, and death of the negative pressure chambers.

It seems especially proper at this time to honor the memory of Ferdinand Sauerbruch as it was fifty years ago in 1904 that he discovered the method by which he could safely open the pleural cavity of dogs under negative differential pressure.

The danger of thoracic surgery in those days was the occurrence of pneumothorax upon opening the pleural cavity. This word was coined by an English physician named Hewson. In 1902 there was no reliable and consistently practical method of overcoming this pneumothorax.

Sauerbruch became an assistant of Professor von Mikulicz at the Surgical Clinic in Breslau, Germany, on Oct. 1, 1903, when he was only 28 years of age.

Professor von Mikulicz was greatly interested in the development of a method of making thoracic surgery feasible. He encouraged and stimulated young Sauerbruch to investigate this problem. Sauerbruch published his autobiography *Das War Mein Leben* in 1951. In it, he tells the story of awakening one night and conceiving the idea of how to overcome the deadly pneumothorax. He suddenly realized what had to be done in his experimental work on dogs to prove his theory. It was purely a physiological problem. It was a question of negative differential pressure. The apparatus he built and developed in 1904 proved successful. He had thereby discovered a safe method of performing surgery within the thorax.

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Sauerbruch's first research and construction of an apparatus began in October, 1903 This was a primitive apparatus (Fig 1) He operated upon several dogs successfully However, the first time he tried to demonstrate the apparatus to von Mikulicz, by opening the pleural cavity of a dog under negative pressure, there was a leak in the rubber cuffs and the negative pressure was lost The lung of the dog collapsed due to pneumothorax and the dog died, to the dismay of both Sauerbruch and von Mikulicz Sauerbruch had purposely opened both pleural cavities

The second apparatus was constructed of wood (Fig 2) There was a glass top Two persons could work within this wooden box for two hours at a time but no longer on account of the intense heat that developed inside the cabinet The third larger box contained 14 cubic meters of air space Five persons could be within this chamber (Fig 3)

Professor von Mikulicz invited his young assistant Sauerbruch to be his guest at the following meeting of the German Surgical Society in Berlin on April 6, 1904 Sauerbruch read his paper and demonstrated the apparatus They had performed 78 operations on dogs Thoracotomy had been completed without mortality The operations had been performed by von Mickulicz with Sauerbruch in control of the negative pressure They had found that minus 10 mm Hg of negative pressure sufficed to prevent pneumothorax This was equivalent to operating at an altitude of 300 meters Surgeons and assistants could easily stand this degree of negative pressure Sauerbruch stated at that time that it was his opinion that human beings could likewise undergo thoracic surgery if negative differential pressure was employed

It is of historic interest that Willy Meyer, the Founder of the American Association for Thoracic Surgery, visited von Mikulicz and Sauerbruch in Breslau in the summer of 1904 Sauerbruch invited Willy Meyer to be inside the negative chamber and witness a transthoracic resection of the esophagus on a dog Willy Meyer reported this fascinating experience before the New York Surgical Society on Dec 14 1904 His paper was published in the *Annals of Surgery* 41 667-685, 1905

Following the meeting of the German Surgical Congress von Mikulicz had an even larger negative chamber built This one was adequate for operations on human beings At first 13 operations on the esophagus were performed on dogs in this chamber He then felt that they were ready for surgery on human beings under negative pressure The first patient had a carcinoma of the esophagus The patient died during the operation The second operation in the negative chamber was for the removal of a tumor of the mediastinum This patient survived

It was at this time that several positive pressure apparatuses were constructed in other clinics in Europe This fact quickly followed Sauerbruch's presentation before the German Surgical Congress Brauer of Heidelberg constructed a mask type apparatus Von Mikulicz had previously employed

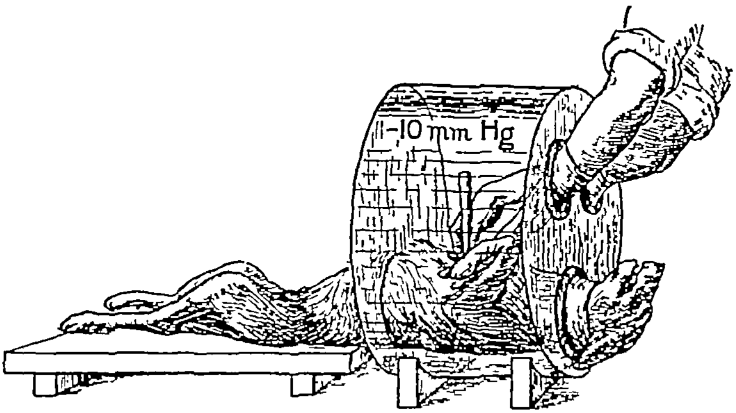


Fig 1 —Sauerbruch s original primitive apparatus for negative pressure. (Fig 1 3 copied from Sauerbruch s early articles)

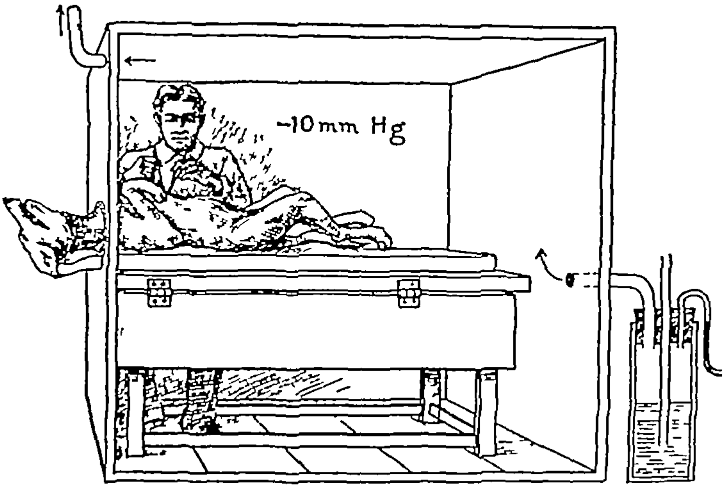


Fig 2 —Sauerbruch s first wooden chamber designed for operations under negative pressure

a somewhat similar type of apparatus, but found it wanting and greatly preferred to work under negative pressure These positive and negative pressure apparatuses were physiologically diametrically opposite in principle This brought forth discussion and arguments as to which method was preferable for surgery on sick patients Improvements in positive pressure apparatuses were made by such men as Engelken, Tiegel, Brat Schmieden, Seydel, Karewski, and Robinson

Physiologists and surgeons had long before this time overcome pneumothorax in animal experimentation by blowing air into the trachea and then sucking it out Matas and others were pioneers in this work in the late nineteenth century Sauerbruch, however, had greatly advanced thoracic sur-

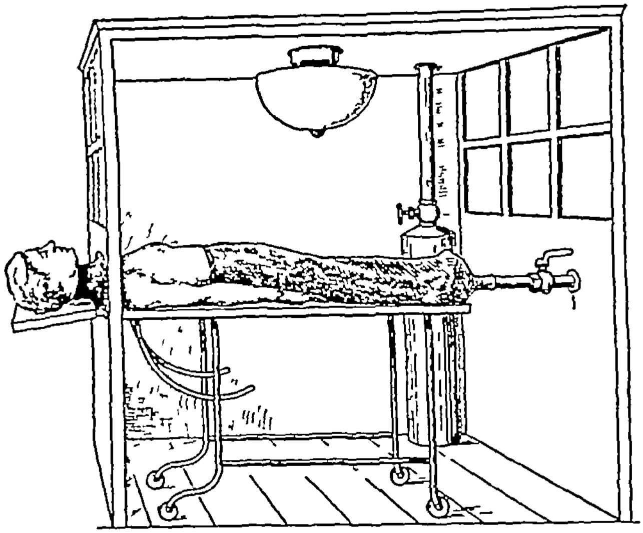


Fig 3.—Early chamber used at the Breslau Clinic for operations under negative pressure. Note that lower portion of the body of the patient is within rubber bag connected with outside atmospheric pressure so that only the chest portion was under negative pressure. It was within this chamber that Willy Meyer witnessed operation on esophagus of dog in 1904.

gery by developing the negative differential pressure chamber. It made normal administration of general anesthesia possible. There was, however, no chamber or apparatus in which it was possible to determine whether negative or positive differential pressure was the preferable method for the sick patient.

In 1905, while this fascinating, new research work was progressing, Professor von Mikulicz died of carcinoma. This tragedy interrupted this important work. Professor Garré replaced von Mikulicz in Breslau. Sauerbruch was transferred to Greifswald under Professor Friedrich. In 1907, both Friedrich and Sauerbruch were moved to Marburg, where surgery under negative pressure was resumed.

In 1908, the Section on Surgery of the American Medical Association invited Sauerbruch to come to the United States to present a paper and demonstrate the negative chamber. Sauerbruch accepted this invitation. He arrived in New York City and brought along the negative chamber. Willy Meyer met him at the pier in New York and acted as his host. The American Medical Association met in Chicago that year. The negative chamber was shipped to Chicago. Sauerbruch read his paper and demonstrated the negative chamber.

Sauerbruch told Willy Meyer in Chicago that he did not intend to take the negative chamber back to Germany. He offered to leave it with Willy Meyer in New York so that Willy Meyer could do some experimental work in thoracic surgery on dogs. Thereupon Willy Meyer asked Sauerbruch to consent to operate upon a dog in the chamber while he was in New York City before he sailed for Germany.

For the authenticity and completeness of the story that follows, I am indebted to Dr Thomas Rivers, Director of the Rockefeller Institute for Medical Research in New York, and to Mr E B Smith, the present Business Manager of the Institute They kindly permited me to review some of their old records of those exciting days

On May 29, 1908, Willy Meyer wrote to Dr Simon Flexner, at that time the Director of the Rockefeller Institute, and asked for permission to erect the negative chamber at the Institute so that Sauerbruch could operate upon a dog before he sailed for Germany Inasmuch as Willy Meyer was not a member of the Scientific Staff of the Rockefeller Institute, it was most gracious on the part of the Directors to grant this permission Therefore, Sauerbruch operated upon a dog's lung under negative differential pressure on the morning of June 11, 1908, at the Rockefeller Institute Willy Meyer assisted Sauerbruch at this operation Among invited guests were the heads of the various departments of the Rockefeller Institute They were Drs Samuel Meltzer, the first President of the American Association for Thoracic Surgery, Alexis Carrel, E L Opie, and Dr Levene Following this operation, the chamber was dismantled and stored in the basement of the Institute

Dr Flexner thereupon kindly made arrangements so that Willy Meyer could start research work in this entirely new field of thoracic surgery at the Rockefeller Institute Willy Meyer, however, had to pay for the dogs and also engage an attendant for the care of the dogs, and pay his salary The Institute allotted him space for the erection of the chamber

During the ensuing summer of 1908, Willy Meyer asked his brother, Julius Meyer, a mechanical engineer by profession, to tour Europe and visit every clinic where work was being done in thoracic surgery All types of positive pressure apparatuses and the negative chamber were studied

Willy Meyer had already decided to build his own chamber in which he could evaluate the pros and cons of negative differential pressure and positive differential pressure The basic plan of action and specifications were

1 To construct an apparatus in which any operation could be performed without moving the patient, whether negative or positive pressures were employed The change from one pressure to the other had to be accomplished quickly

2 There should be no change of position of the patient, surgeons, and anesthetist during the operation

3 The administration of general anesthesia was to be a simple procedure under either negative or positive pressure

4 The operation was to be performed under lower barometric pressure than the prevailing atmospheric pressure existing at the time of the operation

Julius Meyer returned from Europe in September, 1908 After many conferences between the brothers, work was started on a positive pressure chamber This work was accomplished with the great aid of Mr Robert Kny, the head of the Kny-Scheerer Surgical Instrument Company in New York The factory was situated in New York City

The capacity of the first chamber was 80 cubic feet This chamber was large enough to comfortably hold two anesthetists It had an antechamber lock division with doors permitting change of pressure from positive to atmospheric pressure so that one of the anesthetists could leave the positive pressure chamber at any time An adjustable guillotine partition with large rubber cuff surrounded the patient's neck for airtight closure By means of motor pumps and valve action the degree of positive pressure was easily regulated Atmospheric pressure could be easily changed to 10 or 15 mm Hg positive pressure Artificial respiration or inflation of the lung could be started by the simple control of the valve action This allowed the lung to collapse and also to expand in a way similar to that with present-day intratracheal anesthesia with controlled respiration This chamber was completed by the end of 1908 It was transferred to the Rockefeller Institute in January 1909 (Fig 4) Experimental surgery on dogs was started at that time The records of the Institute show that the cost of a dog was 35¢ at that time Mr Smith tells me that today a dog costs $6 50

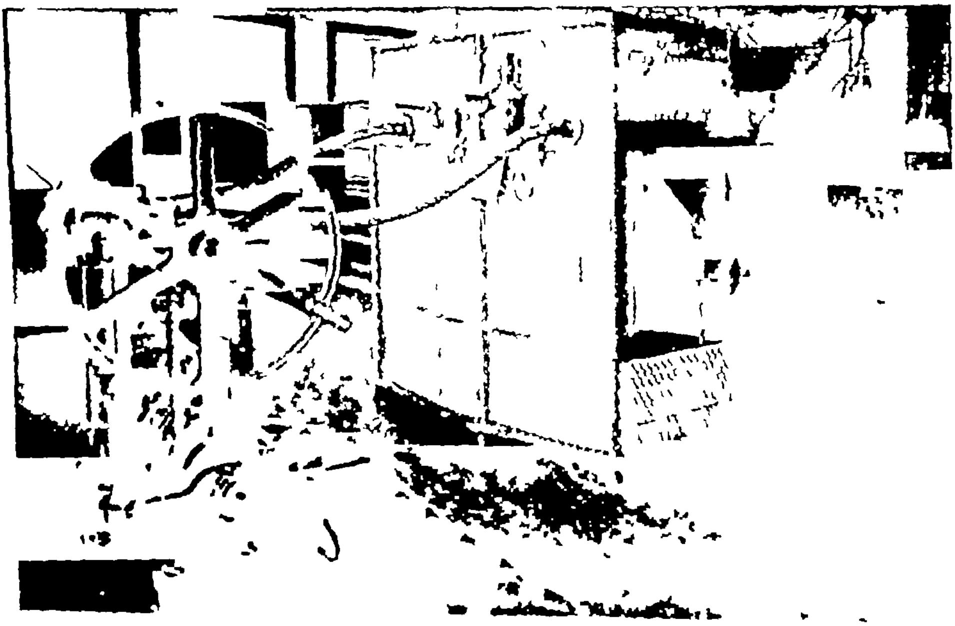


Fig 4—First positive pressure chamber of Willy Meyer used at the Rockefeller Institute for Medical Research for experimental surgery on dogs Note positive pressure electric pump and emergency hand geared pump in case of electric failure

Every Tuesday and Friday afternoon were set aside by Willy Meyer to go to the Rockefeller Institute for experimental surgery on dogs on the lungs esophagus and the heart As a boy of 12 years of age, I was permitted to accompany my father on Friday afternoons after school hours I either sat inside the positive chamber with the anesthetist and learned about anesthesia, or I stood outside and observed operations on the intrathoracic organs Sometimes I was allowed to handle the valves that regulated the positive pressure Therefore, my personal interest in thoracic surgery extends over a period of 47 years

After four weeks of experimental work, the positive chamber was dismantled and moved to the German Hospital, now the Lenox Hill Hospital Early in 1909, the first operation on a human being was performed on the lung of a child This positive pressure chamber was dismantled, transported, and erected four times within the following six months It could be dismantled within a few hours and erected within a day In June of 1909, the chamber was transported to Philadelphia It was demonstrated at the Jefferson Medical College Hospital at the time of the annual meeting of the American Surgical Association in Philadelphia

A second positive pressure chamber replaced the first at the Rockefeller Institute Experimental thoracic surgery on dogs was continued

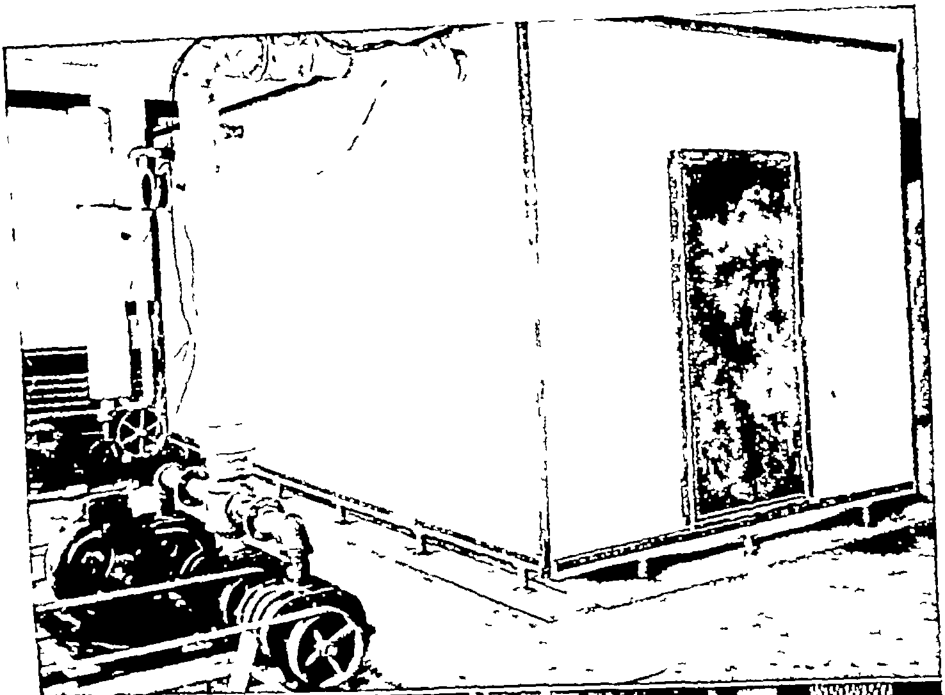
In the meantime the Universal Negative Pressure Chamber was being constructed at the Kny-Scheerer factory This chamber contained 1,000 cubic feet of air Four silent muffled suction pumps sucked the air out of this large chamber Negative pressure was obtained by regulating the inflow of outside air into the chamber through a large inflow pipe whose diameter was regulated by valve action The negative pressure could be brought from atmospheric pressure to a differential of minus 15 to minus 18 mm Hg within a few moments It was quickly found that about minus 7 to minus 8 mm Hg was the ideal negative pressure for thoracic surgery

A positive pressure chamber had been placed at the far end, inside the negative chamber The head of the patient and the two anesthetists were inside this smaller chamber The body of the patient, the surgeon, his assistants, the instrument nurses, visitors, and engineer to control the valves were inside the larger negative pressure chamber All in all, as many as 15 persons could be inside the larger chamber If desired, therefore, 17 persons could be inside the Universal chambers, besides the patient

This Universal Negative Chamber was brought to the Rockefeller Institute in May of 1909 On May 7, 1909, the first operation was performed on a dog This operation was a pneumonectomy (Figs 5 and 6)

One can readily see the advantages of the Universal Chamber When there was minus 7 mm Hg negative pressure in the chamber, the pleural cavity could be opened without collapse of the lung because the dog was breathing normal atmospheric pressure which was inside the smaller chamber This could be interpreted as if the mouth of the dog were at sea level and the opened pleural cavity of the dog at an altitute of about 300 feet above sea level If the differential pressure was to be changed, all that had to be done was to increase the pressure inside the smaller chamber to positive pressure

Fig. 5



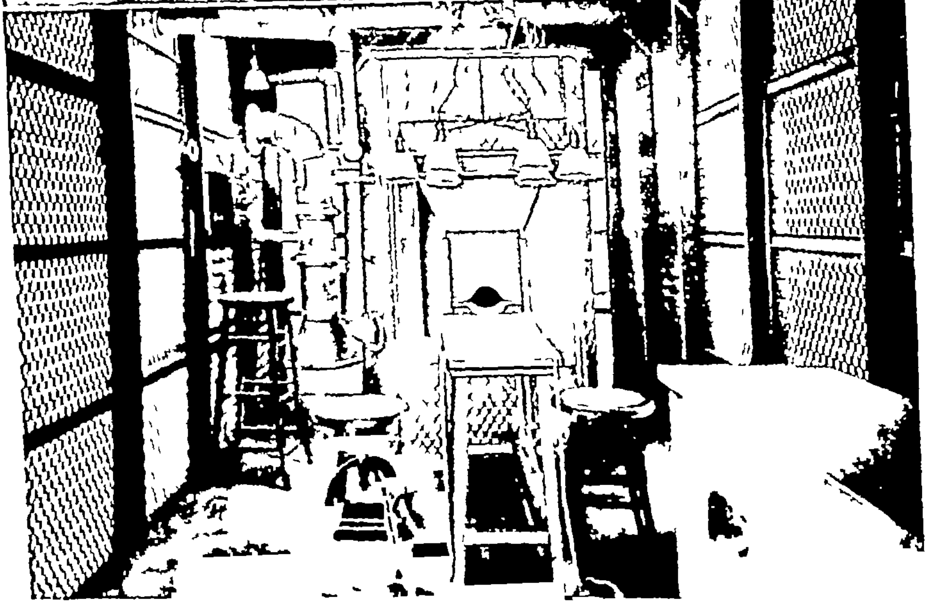
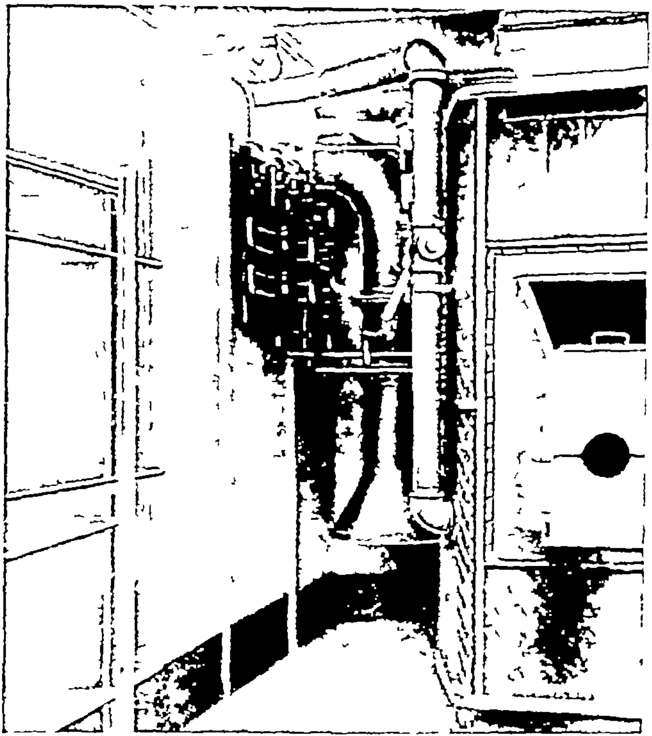


Fig. 6

Fig. 5.—First experimental Universal Negative Chamber erected in the Rockefeller Institute for experimental surgery on dogs. Outer view. Note exhaust pumps in foreground and positive pressure pump in rear. Cover of chamber is balloon material.

Fig. 6.—Inner view of first Universal Negative Chamber. Note positive chamber within the negative chamber. Operating table for dog surgery in front of positive chamber. Note wire frame of chamber with balloon material outside.

Fig 7



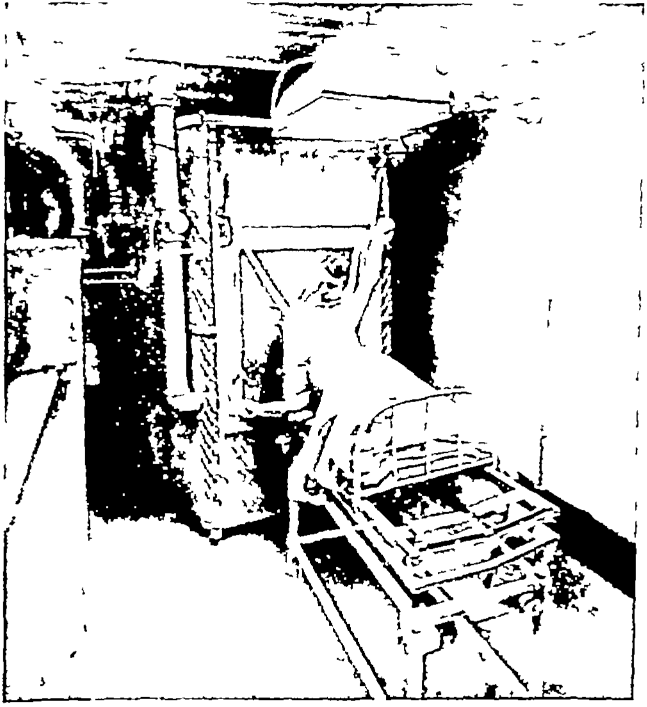


Fig 8

Fig 7—View of interior of Universal Negative Chamber as erected in the Pavilion for Thoracic Surgery at Lenox Hill Hospital Note metal lining instrument panel valve handles for regulating negative pressure in rear large inlet pipe and handle for positive pressure on inlet pipe in foreground Electric control panel on side

Fig 8—Operating table and patient in negative chamber Anesthetist within positive chamber Instrument stand in foreground on left.

and lower the negative pressure inside the larger chamber to atmospheric pressure This change of pressures was possible within a few moments Once the negative pressure in the larger chamber was at atmospheric pressure, the door to the outside could be opened and personnel could go in and out of the chamber The ventilation of air inside the large and small chambers was excellent The air was cool and there was a complete change of air in both chambers every two minutes

Experimental surgery on dogs was continued at the Rockefeller Institute by Willy Meyer from the fall of 1908 until Dec 31, 1913

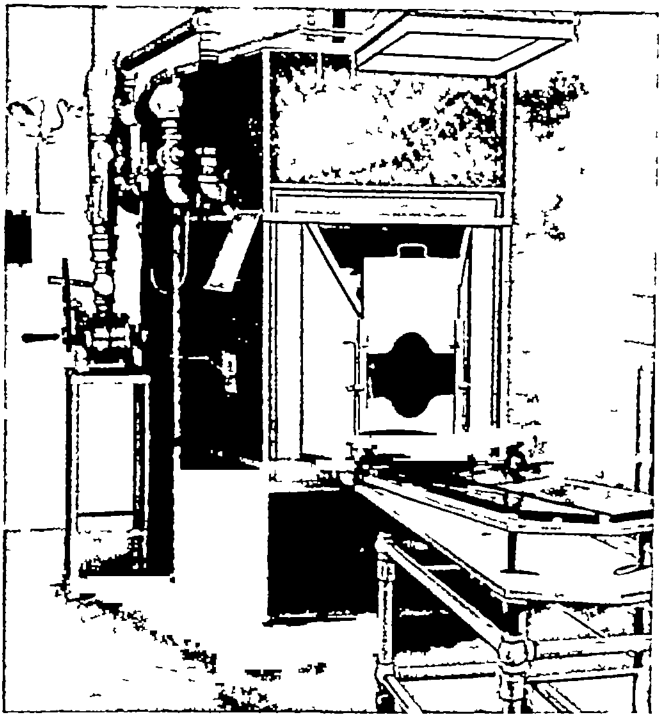
At the suggestion of the attorneys of the Rockefeller Institute, and of the Executive Committee of the Institute, Willy Meyer and Julius Meyer applied for a patent on the Universal Chamber This patent was granted on Jan 2, 1912 The patent issued was No 1,013 800 It read "Apparatus for Conducting Thoracic Operations" This patent was obtained in order to avoid possible priority interference with the use of the apparatus Willy Meyer assigned the patent to the "People of the United States"

During this time, plans were instituted to build a Thoracic Surgery Pavilion at the German Hospital Mr J Pierpont Morgan was one of the first contributors to the fund This generous donation was given through the kindness of Dr James Markoe, one of Willy Meyer's close friends The Trustees of the German Hospital and many friends and patients of Willy Meyer also generously contributed to the building fund. The Department was completed and opened in April, 1911 (Figs 7, 8, 9) It was the first and remained the only such specialized department for thoracic surgery in the United States It housed the Universal Chamber, a positive pressure chamber, as well as other types of positive pressure apparatuses known at that time During the experimental stage of the Universal Chamber at the Rockefeller Institute, a balloon-type rubber cloth enveloped the negative chamber This was changed to a more durable metal covering when the chamber was erected at the German Hospital The inside walls were also made smooth with thin metal This made it possible to wash down the inside walls of the chamber for cleanliness

I am proud and happy to mention that Dr Carl Eggers one of our past Presidents of the American Association for Thoracic Surgery, is probably the only living surgeon who frequently assisted Willy Meyer in the Universal Chamber at the German Hospital by being the anesthetist at many of the difficult operations This was during the early and exciting days of thoracic surgery on human beings (Figs 10 11 and 12)

World War I broke out in 1914 It was very soon discovered on the battlefields in the front line hospitals and in the base hospitals that these complicated apparatuses were not necessary for thoracic surgery An efficient positive pressure anesthesia apparatus properly employed was all that was necessary It was conclusively demonstrated that positive pressure was as efficient as negative pressure It fulfilled the demands of the thoracic surgeon

Fig 9



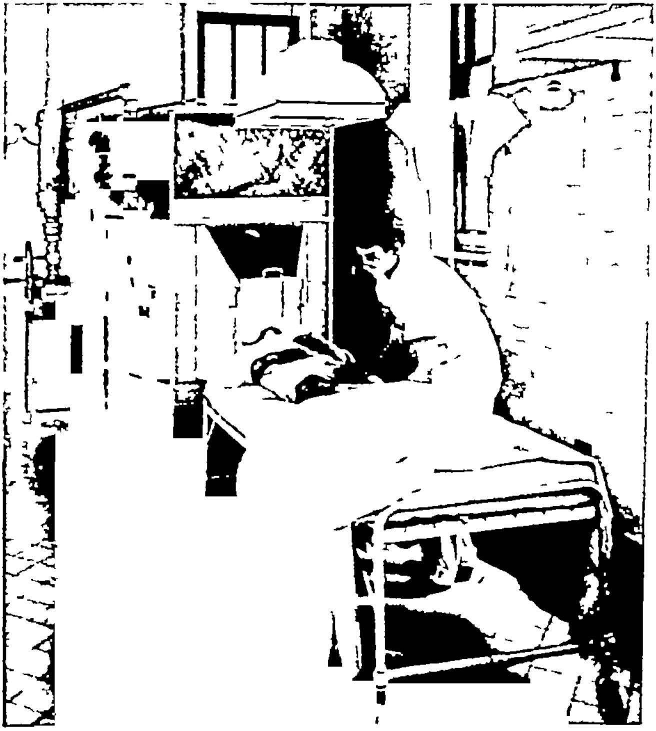


Fig 10

Fig 9—Positive chamber in Thoracic Pavilion at the Lenox Hill Hospital

Fig 10—Photograph of patient on bed under positive differential pressure during post operative treatment. Head of patient and nurse within positive chamber Orderly and body of patient and thoracic cavity with free drainage of chest cavity outside under atmospheric pressure

Fig 11

Fig 12

Fig 11—Vault type of metal door leading into Universal Negative Chamber at the Thoracic Pavilion in the Lenox Hill Hospital Note metal outside covering and large exhaust pipe leading to exhaust motors in engine room

Fig 12—Four muffled silent exhaust vacuum pumps and one positive pressure pump in engine room of the Thoracic Pavilion of the Lenox Hill Hospital

In 1923 the Lenox Hill Hospital needed more space for an expanding x ray department The Trustees of the Hospital decided that the Thoracic Pavilion space would be ideal for this department Therefore, the Universal Negative Chamber—the only one in existence in the world—had to be dismantled Willy Meyer offered it to the Rockefeller Institute on June 19 1923 for further experimental work The offer had to be declined also on account of lack of space The Universal Chamber and the two positive pressure chambers were therefore dismantled and the metal was sold by the Hospital as scrap metal I have often thought that it was a pity that this unique and ingenious Universal Chamber was not offered to the Smithsonian Institute in Washington, D C It was a brilliant conception of an apparatus that very closely simulated the normal physiology of the thoracic cavity It certainly was more physiological than any positive pressure method If a negative chamber were available today it would be fascinating and interesting to speculate experiment and see whether it might not be of real value in the surgery of modern heart lesions especially in the very ill cardiac patient

All honor therefore to the memory of those great pioneers in thoracic surgery and to the contributions which they made in those early days of this fascinating chapter of surgery

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Erratum

The title of the article by William G Childress, M D, and George C Adie, M D, which appeared in the May, 1955 issue of the JOURNAL, pages 480 487, should be "Recurrent Plasmacytoma of the Mediastinum" rather than "Recurrent Plasmacytoma of the Lung"

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty sixth Annual Meeting of the American Association for Thoracic Surgery will be held May 7, 8 and 9, 1956, in Miami Beach, Florida Headquarters will be at the Hotel Fontainebleau

Requests for Hotel Reservations

These should be mailed directly to Mr Jack Slone, Director of Sales, Hotel Fontainebleau, Miami Beach, Florida Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure If accommodations are desired elsewhere in Miami Beach, please communicate directly with the hotel of your choice

Thoracic Surgical Forum

The Thoracic Surgical Forum will be continued as a special session at the 1956 meeting The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies and modified or new surgical techniques The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferral to the Regular Program

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper

All Thoracic Surgical Forum papers will be published together in one issue of the JOURNAL Maximum length 3000 words without illustrations If illustrated, an appropriate number of words must be subtracted for each cut used

Abstracts for Papers

Abstracts for the presentation of all papers at the 1956 meeting must be received on or before Dec 15 1955, otherwise they will not be considered by the Program Committee

Abstracts should be labeled "For Thoracic Surgical Forum," or "For Regular Program" The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper

Five repeat five copies of *each* abstract must be sent to the Secretary of the Association, Dr Paul C Samson 3959 Happy Valley Road Lafayette, California They should not be sent to the Editor

Those on the program are reminded that papers presented at the meeting *must* be handed to the Secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in the JOURNAL OF THORACIC SURGERY

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis *The films themselves*, together with descriptive material concerning length of presentation etc must be received by Dr Julian Johnson, University Hospital, 3400 Spruce St Philadelphia 4 Pa before Dec 15, 1955

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec 15, 1935, otherwise, the applications will be deferred for consideration until the 1937 meeting

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

The Journal of Thoracic Surgery

VOL. 30 AUGUST, 1955 NO. 2

Original Communications

REDUCED INTRATHORACIC CIRCULATION AS AN AID IN ANGIOCARDIOGRAPHY

AN EXPERIMENTAL STUDY

I. BOEREMA, M.D., AND J. R. BLICKMAN, M.D.
AMSTERDAM, THE NETHERLANDS

THANKS to great technical improvements, angiocardiography has become, in latter years, an indispensable diagnostic procedure. Rapid serial exposures in two planes, if necessary, have made this method almost a routine matter.

It must be conceded, however, that under the present circumstances, when diagnostic investigations are requested in regions close to the heart, the number of difficulties encountered increase with the proximity to the heart.

These difficulties may be summed up as follows:

1. The velocity of the blood stream in heart and major vessels is such that the injected contrast medium is rapidly dispersed. A rapid injection under high pressure is therefore necessary. High percentages of iodine are indicated in order to achieve adequate contrast. If these contrast media inadvertently reach the organs before being dispersed, serious complications may follow. Accidents involving the cerebrum, kidney, and coronary vessels have been described.

2. The contrast medium is carried off very rapidly by the blood stream. This makes high-powered, expensive apparatus an absolute necessity. Even serial exposures of 12 per second do not always give adequate information.

3. Sharp contours are extremely difficult to obtain owing to the great mobility of the walls of the heart and vessels during the cardiac cycle. Very short exposure times do not prevent a certain haziness.

4. Quick injection necessitates pressures well over the normal systolic pressure present in the vessels. Whether any untoward effects may be expected from these sudden increases in pressure is not known.

From the Surgical Clinic of the University of Amsterdam at the Wilhelmina Gasthuis (Chief: Prof. Dr. I. Boerema).

This experimental work was made possible by the financial aid of Toegepast Natuurwetenschappelijk Onderzoek.

Received for publication Feb. 18, 1955.

These difficulties, however, would cease to exist if it were feasible to reduce the blood flow through the heart for a short period. If the blood flow would cease or be greatly reduced, little or no dispersal of the contrast medium would occur, and the time in which injection and exposures could be made would be longer. The use of highly concentrated contrast media could be abolished, reducing the danger of the above-mentioned complication. Reducing the blood flow through the heart would lower the blood pressure, which in its turn would make injection under high pressure unnecessary. The possible danger of increased intra-arterial pressure—in sometimes already diseased blood vessels—must be borne in mind.

In order to slow down or completely interrupt the blood flow through the heart and the great vessels near this organ, we applied knowledge gathered during the last three centuries concerning the influence of the respiration on the blood flow in the thorax.

Swammerdam in the seventeenth century believed that alternating inspiration and expiration were necessary for maintaining the blood flow in the capillaries of the lungs.

During the first half of the nineteenth century there were conflicting views concerning the influence of respiration on the blood flow in the thorax. Some investigators concluded from experiments that cessation of normal respiration was followed by a fall in blood pressure, while others were of the *opinion that such respiratory arrest had no influence on the blood pressure* and the frequency of the heartbeat as estimated from the radial pulse.

Weber in 1850 *found an explanation for these contrasting views.* According to him they were dependent on whether the glottis was open or closed during cessation of respiration. When the glottis was open, there was no interference with the blood flow. When, however, the glottis was closed after an inspiration, the expiratory muscles compressed the thorax so that the organs within it were also compressed. This had a great influence on the blood stream. From experiments on himself he showed that compression of his own thorax after deep inspiration and closure of the glottis was followed almost immediately by complete disappearance of the radial pulse. The heartbeat disappeared immediately, whereas the radial pulse could still be felt weakly for 3 or 5 beats before disappearing totally. Weber concluded that compression of the contents of the thoracic cavity and of the air filled *lungs caused cessation of the heartbeat and almost immediate disappearance* of the pulse.

Weber in the experiment on his own body compressed the air in the lungs and in the bronchi. He concluded not only that this gave an impetus to the blood stream through the capillaries of the lungs but also that the pressure on the lungs because of their elasticity was brought to bear upon the heart and the great vessels. The right atrium and the venae cavae were especially *compressed and the tension of the blood in them was thereby raised,* so that a damming up of the venous blood stream in the great veins outside the thorax resulted. Normally the pressures in the venae cavae and the right atrium are so low that even the low pressure in the great veins is sufficient to bring the blood into the right atrium Therefore, during compression of the thorax after inspiration with a closed glottis, there is no filling of the heart and the flow through the right heart is blocked The first following heartbeats will still pump the blood that comes from the lung vessels to the left heart, into the aorta and after this the flow into the left heart is blocked also This is the explanation for the 3 or 5 weak radial beats which may be felt after the beginning of the compression of the thorax Immediately after compression of the thorax was discontinued and the glottis was again open the normal pulse reappeared

Weber confirmed the view of Valsalva, who in the seventeenth century wrote 'If after a deep inspiration a strenuous and prolonged expiratory effect be made against a closed glottis the pressure so exerted on the heart and greater vessels arrests the flow of blood through the lungs ' But Weber went further and stated that not only the blood flow through the lungs was arrested but also, and primarily the flow through the intrathoracic venae cavae and the right heart was arrested, it is thus primarily a true tamponade of the right heart The observation of Valsalva drew no attention for two centuries but the writings of Weber who was unaware of Valsalva's discovery was the cause of many experimental clinical and pathological papers on this subject even up to the present day

Ten years after Weber's communication Einbrodt (1860) showed by animal experiment that increasing the pressure in the lungs by blowing air in the trachea produced the same result as blocking the blood flow from the venae cavae and the right heart by use of the Valsalva test in men

Sauerbruch's explanation of the Valsalva test was that it was due to a blocking of the blood flow through the lungs by compression of the smaller blood vessels in the alveolar walls He thought that the pressure exerted on these vessels was the same as the pressure of the intrabronchial air and that the pressure on the heart and great vessels was the tension of the intrabronchial air minus the contractile force of the elastic lung tissue

Humphreys and associates (1937) showed in experiments on dogs that the cardiac output decreased when the intratracheal pressure was increased These workers measured the blood pressure in the heart and in the great vessels From their experiments they believed that the decrease in cardiac output was caused by compression of the right heart interfering with its filling rather than by compression of the pulmonary vessels interfering with the emptying of the lung vessels This was an experimental confirmation of the deduction of Weber formulated nearly a century earlier

Our roentgenological research on this problem now shows that Weber was exactly right that high intrabronchial pressures do not block the blood flow through the lungs but compress the right heart and the venae cavae It is strikingly remarkable that Weber from his simple experiment was able to describe the sequence of events occurring in the thorax which can now be demonstrated with the aid of operative experimental surgery and of roentgenology No important addition could be made to Weber's deductions Making use of this knowledge, we intended to fill the heart and the large intrathoracic vessels with a radiopaque fluid during the slowing down or even the arrest of the blood flow as described by Valsalva and Weber

However, before starting this study in the field of roentgenology, we first tried to verify the fact that the fall in arterial blood pressure which accompanied an elevation of intrabronchial air pressure was not due to compression of the capillary bed in the lungs (as was the opinion of Sauerbruch), but that the tamponade or blocking of the venae cavae and the right heart was the primary cause (as was the meaning of Weber) If the first concept were correct, then increasing the intrapulmonary air pressure might give rise to an acute cor pulmonale, bringing the right heart of the patient into a precarious state Furthermore, a greatly increased intrathoracic pressure might prove a danger because of the anemic state of all organs during this period of lowered blood flow Heart and brain particularly might be damaged Weber stated that when he continued his experiment for more than sixty seconds he became completely unconscious He also thought that complete arrest of the blood stream might be extraordinarily dangerous Weber ascribed to this mechanism many cases of suicide due to cessation of respiration

The Valsalva test in man differs greatly from the condition caused by insufflation of air into his lungs The Valsalva test and also the "fitness" test (Flack) of blowing against a column of mercury of 40 to 60 mm, necessitate a forceful contraction, not only of the thoracic muscles, but also of the muscles of the abdominal wall Under such conditions the diaphragm is not an essential septum between the abdominal and the thoracic cavity When air is inflated into the lungs of an anesthetized animal only the thoracic cavity is involved The blood flow from the abdomen to the thorax must be quite different in both conditions (Nordenfeld)

We now know that the blood stream to the heart and brain can be blocked for 2 to 4 minutes without danger, therefore, a block for 30 to 60 seconds as in our experiments, would not be expected to be dangerous at all Nevertheless, we tried to elucidate the following points by animal experiment, before starting our roentgenologic study

1 Does an intrabronchial pressure increased to 60 cm water diminish the blood flow from the left heart sufficiently for our purpose?

2 How does the blood pressure in the right heart react to such an increased intrabronchial pressure? Is the decrease in left ventricular output to be attributed to compression of the pulmonary capillary bed or to a decreased filling of the right ventricle when the intrabronchial pressure is raised to 60 cm water? In other words, does danger of acute cor pulmonale exist?

3 Does the danger of myocardial ischemia exist within a time limit of 60 seconds or after repeated drops in blood pressure?

4 Is it technically feasible to inject the contrast medium in a period of suppressed circulation? Does a smaller amount of contrast medium containing a smaller percentage of iodine give better results than methods currently employed?

5 Does this method give better information about conditions existing in the circulatory system?

The answers to these questions follow in numerical order

1 Anesthesia was started with intravenous veterinary Nembutal The trachea was intubated with a cuffed tube A water manometer was placed in the anesthetic circuit so that exact control of the pressure exerted by manual compression of the bag was possible Through the right carotid artery a polyethylene catheter (exterior diameter 3 mm) was passed into the ascending aorta Direct blood pressure readings were obtained with increasing intrabronchial pressure (Fig 1) Until the intrabronchial pressure reaches 30 cm water no important changes can be seen, over 30 cm intrabronchial pressure the blood pressure decreases rapidly until at 60 cm pressure no pulsations are present at a basic value of 20 mm Hg The first question can be answered in the affirmative On increasing intrabronchial pressure to 60 cm water the left ventricular output is very much decreased

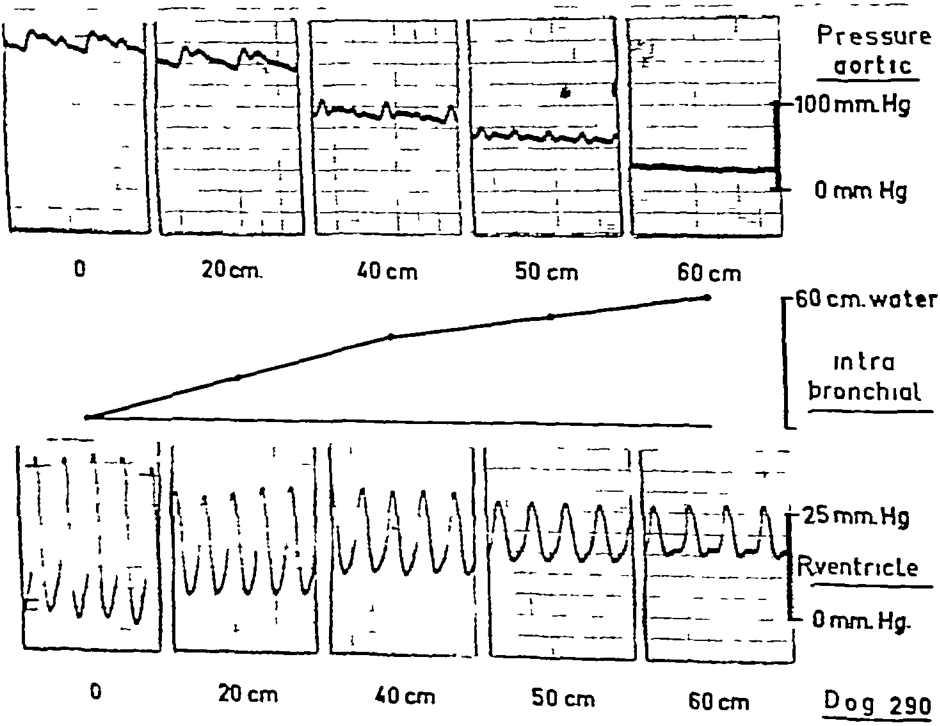


Fig 1—Pressure readings in aorta and right ventricle with increasing intrabronchial pressure

2 In the same dog a catheter was passed down the right jugular vein into the right ventricle Blood pressure readings were taken with increasing

intrabronchial pressure Fig 1 shows the decreasing pressure in the right ventricle with mounting diastolic values The normal value of 34/−3 mm Hg is reduced, at 60 cm water intrabronchial pressure, to 26/14 mm Hg The decrease in systolic pressure in the right ventricle is gradual This confirms the view of Humphreys that the compression of the pulmonary capillary bed cannot be an important factor responsible for the fall in left ventricular output If this were the case, the recording of the right ventricular pressure would show a sharp rise We must conclude from this that the increasing pressure in the trachea to 60 cm water impedes the filling of the right heart

The elevation of the diastolic pressure must be assumed to originate from the elevated pressure in the entire thoracic cavity To demonstrate the influence of the elevated intrathoracic pressure the following experiment was performed

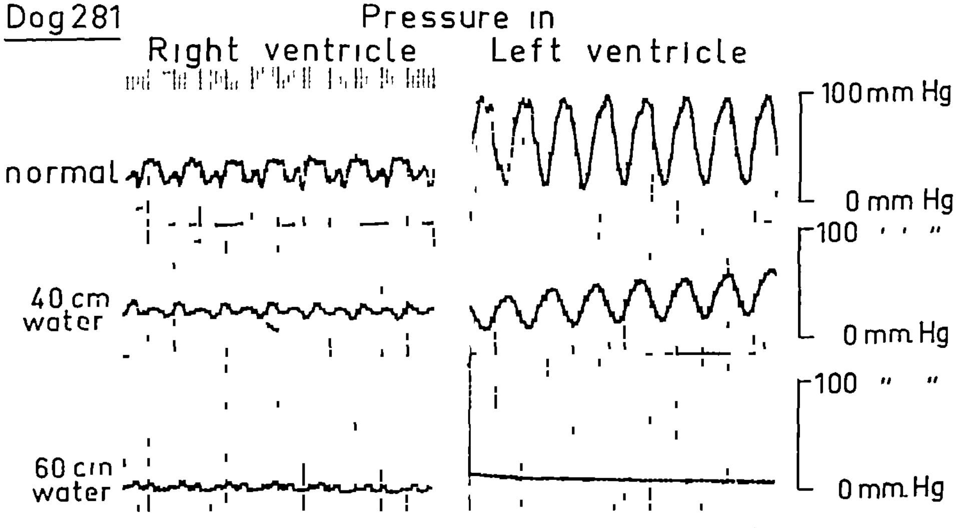


Fig 2—Right and left ventricular pressures after left sided thoracotomy at normal pressure in the bronchi and at pressure of 40 cm and 60 cm water

A left sided thoracotomy through the fifth intercostal space was performed in a dog The pericardium was opened A needle, connected to an Elema pressure recorder was introduced into the left ventricle The left lung was loosely packed with gauze Intrabronchial pressure was raised to 40 cm water (Fig 2) The left ventricular pressure decreased to 50/15 mm Hg After raising the intrabronchial pressure to 60 cm the pressure was further decreased to 5 mm Hg Release of intrabronchial pressure showed a prompt return to normal values The recorder needle was further advanced through the ventricular septum into the right ventricle and readings were taken under the same conditions The decrease in systolic pressure was evident, the diastolic values were not elevated

Apart from the evidence provided by these pressure recordings that acute cor pulmonale need not be feared roentgenologic evidence is also present Fig 3 shows the heart contour under normal conditions and with elevated intra-

Fig. [illegible].—Heart shadow with catheter in right ventricle under normal conditions (A) and with intrabronchial pressure raised to 60 cm of water (B). The compression of the heart in the latter is evident.

Fig. [illegible].—Right ventricle during injection of contrast medium with raised intrabronchial [illegible] The [illegible] [illegible] contrast [illegible] shown and not blocked by the high intrabronchial pressure. The right ventricle remains small when contrast medium is injected (Fig. 4). The difference in size of the inferior vena cava under normal conditions and with inflated lungs may be estimated from Fig. 5. It confirms Weber's statement that not only the right heart but also the venae cavae are compressed by elevation of the intratracheal pressure.

A right-sided thoracotomy through the fourth intercostal space was performed in a dog. A glass tube was inserted into the right atrium through the auricle. The average blood pressure was 4.5 cm. water; increasing the pressure of the air in the bronchi and the lungs caused the blood pressure in the atrium to rise rather high. It is clear that with the right thoracic cavity open, there was no compression of the venae cavae and the right heart, only the capillary bed in the lungs was compressed, which produced a situation as in acute cor pulmonale.

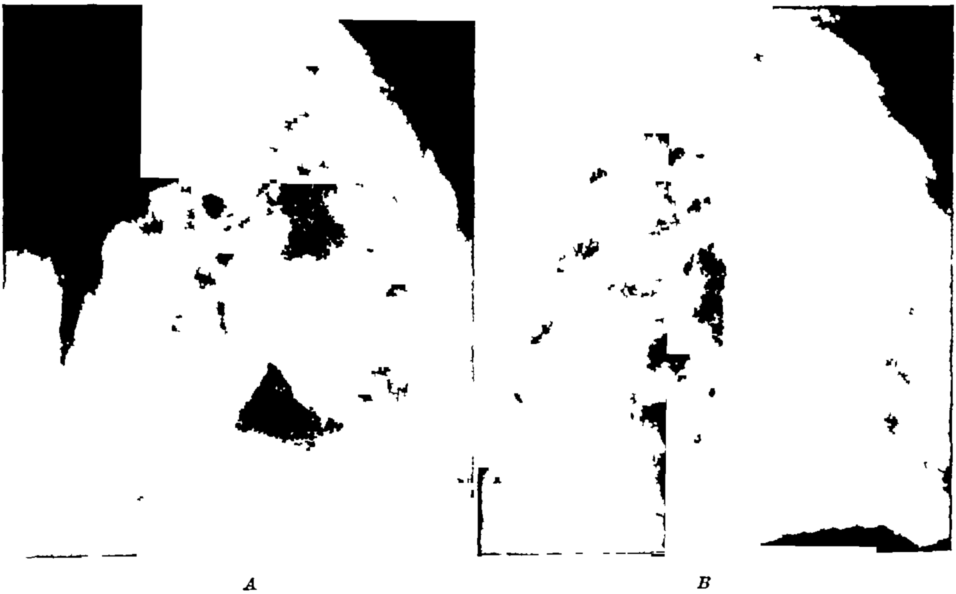


Fig. 5.—Inferior vena cava under normal conditions (*A*) and with intrabronchial pressure raised (*B*). The compression of the vena cava is evident.

We conclude from these experiments that with the thoracic cavity closed (or at any rate the right pleural space) no danger of acute cor pulmonale is present when the intrabronchial pressure is raised to levels between 40 and 60 cm. of water. The venous return to the right heart under these circumstances is primarily greatly reduced.

Meyer Saklad reviewing pressure breathing in surgery states: "A patient in good condition can tolerate a moderate amount of increased intrapulmonary pressure. The patient in a poor physical state cannot. The ability to withstand positive pressure breathing depends to a great extent on the patient's ability to maintain a heightened venous pressure, for during the phasic drop in intrapulmonary pressure the elevated venous pressure is an important factor in filling the right heart."

Hypotension anesthesia might make poor candidates for pressure breathing (Saklad). These dangers, as indicated by Saklad, are caused by an elevation of the intrabronchial pressure of air during a great deal of the period of anesthesia, although interrupted repeatedly.

In our roentgenographic method, the blood flow is impeded by elevation of the intrabronchial air tension only once and for no more than 30 to 60 seconds. It is, therefore, questionable whether the dangers summed up by Saklad, exist in our method.

3. Nevertheless, the danger of myocardial ischemia is undoubtedly present when the left ventricular output is reduced. In most circumstances therefore, we have performed the experiments under constant electrocardiographic control. We have raised the intrabronchial pressure during periods up to 60 seconds. Apart from a temporary reversed T wave, no changes could be observed. According to the cardiologist the changes observed may have been due to axis deviation.

In two instances dogs were sacrificed after the experiment in order to examine the pulmonary tissue. No pathological changes were found in the alveoli and there were no signs of interstitial edema. Fourteen experiments were performed on 10 dogs. There was one death in the series due to heavy overdosage of contrast medium in one of the first experiments. The animal died from cerebral convulsions.

The direct influence of an injection of contrast fluid into the ascending aorta through a tube passing the carotid artery was measured in the aortic arch. When under normal conditions the fluid was injected under pressure the blood pressure was elevated during the injection by 25 to 30 mm Hg. Using the same technique with low blood pressure caused by raised intrabronchial pressure no pressure changes could be recorded. Thus the danger of raising the pressure in the aorta to too high a level during the injection of contrast fluid is eliminated when the intrapulmonary air pressure is raised to 60 cm water.

4. Nuvoli, Rousthoi, Radner, Guglielmo and Guttadauro (reviewing the angiocardiographic material of Jönsson et al.), Helmsworth et al., Wickbom, Pearl, Hoyos and del Campo have shown very encouraging results in animal experiments and in clinical research concerning the visualization of the aortic bulb, the aortic arch and the coronary vessels. Their chief difficulty is the selection of the correct moment for exposure if no apparatus for serial exposures is used.

For these animal experiments we have used a very simple device based on sliding film cassettes with exposure times of 0, 2, 4, 7 and 11 seconds. A Lysholm grid was used. Exposure times varied from 0.04 to 0.06 second. For the injection a pressure syringe as described by Jönsson was used connected with a polythene catheter with an internal diameter of 2.1 mm. The catheter was placed in the ascending aorta through the right carotid artery at a level of 1.5 cm above the aortic valves. The time necessary to inject 20 to 25 c.c. of 45 per cent Pyelombrine was about 2 seconds. The first exposure was made when approximately four-fifths of the total amount had been injected The same technique was used in the dog shown in Fig 6, A and B, with and without raised intrabronchial pressure The difference in quality is obvious

For cardiopneumangiography the technique used was essentially the same The catheter was introduced through the right jugular vein into the right ventricle When the intratracheal pressure was raised to 60 cm water the

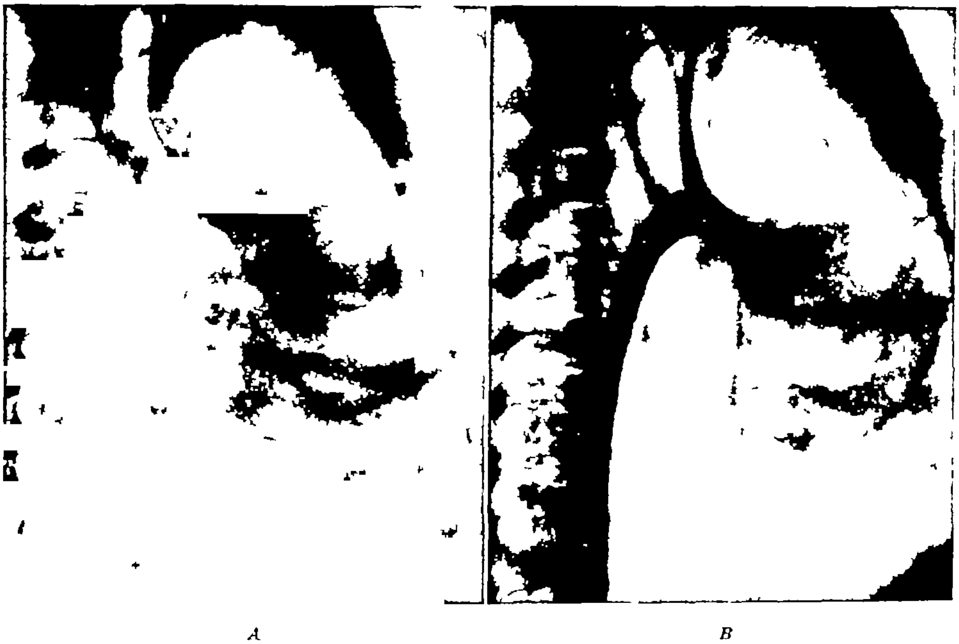


Fig 6 — Aortic arch after injection from brachiocervical trunk under normal conditions (*A*) and with intrabronchial pressure raised (*B*) The latter shows reduction of the size of the heart the aorta and the brachiocervical trunk a sharper outlining a better filling of the bulbus aortae a good visualization of the aortic valves a good filling of the coronary arteries

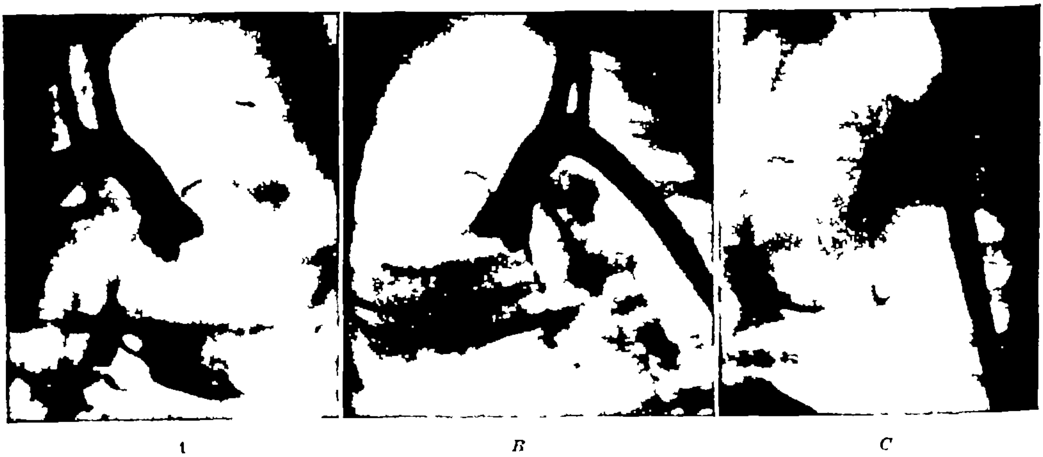


Fig 7 —Coronary arteries (left and right oblique and anteroposterior view) well visualized after raising of the intrabronchial pressure to 60 cm water

contrast obtained in the pulmonary vessels with as little as 20 c.c. of 45 per cent Pyelombrine was excellent even when the time for injection was increased to 6 seconds with the use of a small catheter. Intrabronchial pressure in some later experiments was raised to only 40 cm. water with the same excellent results. When the same techniques were used, but without raised intrabronchial pressure, no clear image could be obtained of the pulmonary vessels.

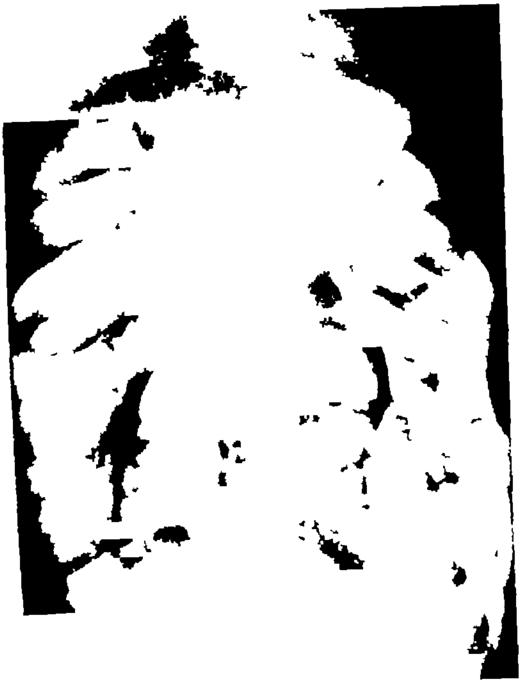


Fig. 5.—Right heart and pulmonary arteries visualized with 20 c.c. of 45 per cent contrast medium during increased intrabronchial pressure. The pulmonary veins are faintly visible.

Some experiments were carried out with high intrabronchial pressure to demonstrate the lowered arterial pressure in peripheral arteriography. It appeared impossible to obtain a filling of the femoral arteries when the contrast fluid was injected in the aortic arch. The contrast medium was retained in the abdominal aorta. Release of the intrabronchial pressure restored passage immediately. Thus, it is also possible with this technique to obtain a good contrast using only a small amount of fluid and injected under low pressure. Excellent nephrograms were obtained by this method.

We may conclude that a technical improvement is obtained by the method described. Small amounts of contrast medium containing a low percentage of iodine injected under low pressure give good results from a technical point of view.

5. By the method described information can be obtained without the use of quick working film changers. This makes angiocardiography possible without expensive apparatus. Filling of the aortic arch and bulb and coronary arteries is readily performed with good visibility (Fig. 6). The reduced

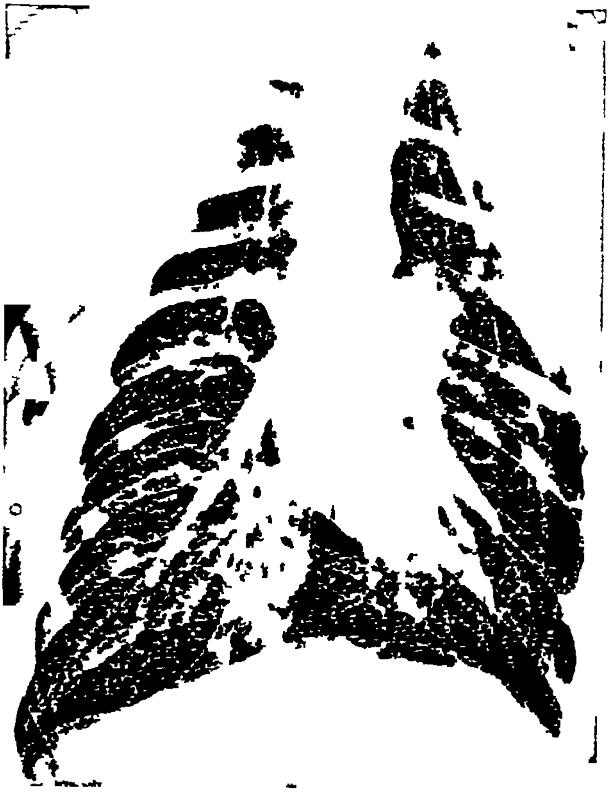
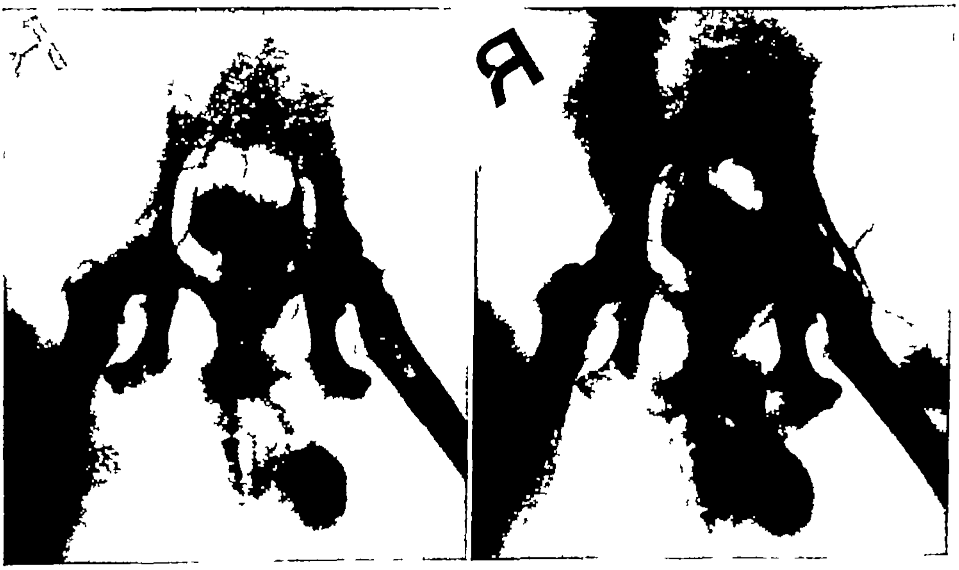


Fig 9.—Pulmonary arteries and veins clearly visible after injection of contrast fluid into the right heart during increased intrabronchial pressure to 60 cm water



A B

Fig 10.—Contrast medium remains in pelvic vessels as long as intrabronchial pressure is raised to 60 cm. water Between A and B there is a period of 12 seconds

movements of the heart and vessels produce much clearer contours The diameter of the aorta is reduced to approximately two-thirds of its normal size The left ventricle gives a clear image when filled The aortic valves can be clearly identified

Filling of the coronary arteries is easily performed even from the aortic arch The time factor is of little interest as the contrast remained unchanged for at least 4 seconds (Fig 7)

With the catheter placed in the right auricle or right ventricle excellent visualization of the right heart, outflow tract, and pulmonary arteries was obtained (Fig 8) Visibility was maintained in the lungs during elevation of the intratracheal pressure for periods up to 5 seconds with a preceding injection time of equal duration In some instances, both pulmonary arteries and veins were visualized simultaneously with a contrast dose of 25 c c of 45 per cent concentration (Fig 9) This proves again that it is not the compression of the pulmonary capillaries which is the most important factor in slowing down of the blood stream when the intratracheal pressure is increased to 60 cm water The use of this method for aortography of the abdominal aorta has not yet been studied extensively The possibility of obtaining peripheral arteriograms by injection of a small dose of contrast medium of low concentration seems attractive Sharper contours should simplify the diagnostic possibilities of vascular lesions Serial exposures of dubious lesions are quite possible as the contrast remains visible for prolonged periods (Fig 10)

CONCLUSION

The roentgenologic study of contrast fluid in the heart and great vessels confirms the views of Weber who stated that elevation of the intratracheal pressure caused a slowing down of the bloodstream through the heart by compression of the right heart and the venae cavae From a practical point of view the advantages of our new roentgenographic method seem considerable not only in the experiments described but possibly also in clinical angiocardiography

The advantages for diagnostic angiocardiography may be summed up as follows A better insight into the pathology of the coronary arteries may be obtained with the possible development of surgical therapy of chronic disorders The roentgenographic approach to congenital abnormalities of the heart may be improved The absence of or change in the difference in pressure between left and right heart may result in a direct visualization of the shunt intra or extracardial after injection of the contrast medium Abnormalities in the region of the aortic arch may be depicted more clearly Pneumoangiocardiography and arteriography of special organs can be performed more easily and with a minimum of danger

The clinical application of our method of roentgenography will be described in detail later

Dawson expressed the opinion that it would be regrettable if the vast amount of experimentation carried out on the work of Valsalva proved fruitless and could not be utilized to human advantage

We think that this experimental study, by means of its clinical application, will provide clearly and simply information which will be of great value in medicine today

SUMMARY

A new method for angiocardiography is described Use was made of slowing of the blood stream through the heart and the fall in blood pressure occurring after increased intrabronchial pressure to values between 40 and 60 cm of water It was shown that this slowing down of the blood flow through the heart was primarily caused by compression of the right heart and both venae cavae Pressure recordings made during this procedure showed that there is no danger of congestion of the right heart Experiments performed in dogs show that clear visualization of coronary arteries, heart chambers, aortic arch and pulmonary vessels is possible with a minimum of contrast medium of low iodine content, injected under low pressure

We are indebted to Mrs D M E Vermeulen Cranch, F F A R C S , and J van Leeuwen, M.D , from the Department of Anaesthesiology, R Lopes Cardozo, M D , and Miss E van *Buuren from the Department of Radiology for their technical assistance*

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THROMBOSIS OF INTERNAL JUGULAR VEIN SECONDARY TO INTRATHORACIC DISEASE

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MEMPHIS, TENN.

IN THE course of performing some one hundred and fifty supraclavicular biopsies for various chest diseases, we have encountered several cases with complete thrombosis of the internal jugular vein secondary to the intrathoracic disease. We would like to give two of these cases in some detail in this presentation, as there is little mention of this complication in the literature.

There are, however, numerous instances reported in which thrombosis of the internal jugular vein occurred secondary to some disease in the lateral sinus or followed operations about the nose and throat.

When a surgeon doing a routine supraclavicular biopsy encounters a thrombosed internal jugular vein, a problem is raised. If the condition is not recognized immediately, an attempt might be made to remove this mass on the false assumption that it was a mass of matted lymph nodes. This could have fatal results. We have used a small needle to aspirate the thrombosed jugular vein when it is exposed at surgery but have been unable to obtain enough material by this means for a Papanicolaou stain. We have considered using a needle with a larger bore for the same purpose and this probably could be done with safety; however, so far we have not tried this.

The cases reported by Dr. Scheshter in his paper entitled "The Superior Venacava Syndrome," although not identical with those we are reporting, are similar enough to be of interest. In searching the literature he found 274 cases of superior vena cava syndrome which were confirmed sufficiently to be of statistical importance. Approximately 75 per cent of all those reported cases were caused either by primary intrathoracic neoplasms, aortic aneurysms, or lymphomas. The cases due to aortic aneurysm have decreased in number in the recent literature. Dr. Scheshter reported twenty-two cases in his series from New Orleans. He stated that almost all cases of superior vena caval obstruction by intrathoracic malignancies were caused by direct invasion of the venous wall by tumor tissue. He found an incidence of 11 per cent involvement and obstruction of the superior vena cava in primary carcinoma of the lung. He concluded that superior vena caval obstruction is not nearly as rare as was formerly believed.

CASE REPORTS

CASE 1.—Mrs. E. V. was a white widow, [illegible] years of age. This patient was first admitted to the Baptist Memorial Hospital, Memphis, Tenn., on Aug. 8, 195[illegible]. For the preceding [illegible] she had [illegible] increased dyspnea, weakness, and a dry hacking cough. She was [illegible] of shortness of breath. She stated she had had "flu" in [illegible] and had not felt well since that time. During the week preceding admission there [illegible]

[illegible]

had been some swollen glands in the neck Anorexia and some weight loss were also noted There were no known tuberculosis contacts and she had no hemoptysis, fever, chills, or night sweats There were no gastrointestinal, genitourinary, or gynecological symptoms.

Physical examination showed the patient to be an elderly white woman, orthopneic but not cyanotic There was a diffuse tenderness over the left side of the neck but no definite nodes were palpable Breath sounds were absent and coarse râles were heard above the right leaf of the diaphragm, with some flatness to percussion in this area, and with scattered fine râles over the left lung There were noted a diffuse tenderness of the abdomen and a questionable liver enlargement There was little change from the condition shown by a previous series of films made at the Houston Hospital, Houston, Miss , on July 28, 1953, through Aug 1, 1953 All the films demonstrated an irregular collection of fluid just above the right diaphragm with questionable enlargement of the right hilar shadow The admission diagnosis was "right pleural effusion of undetermined origin"

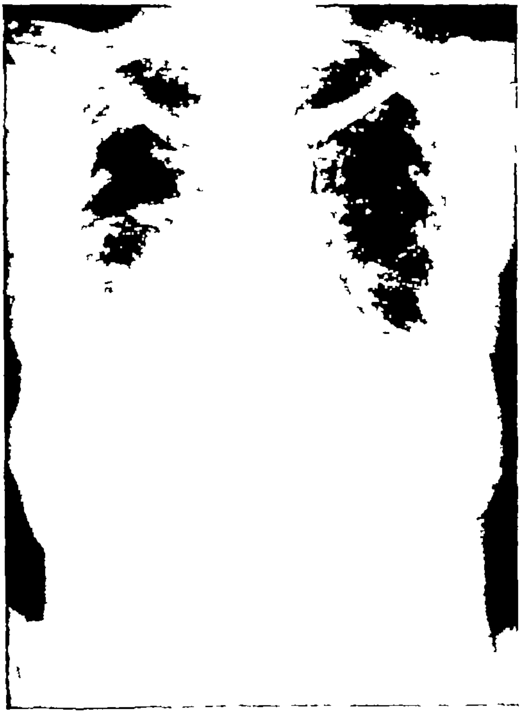

Fig 1

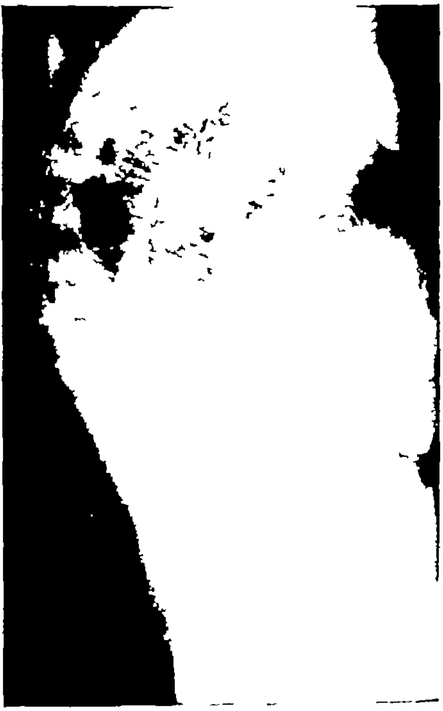

Fig 2

Fig 1 —Case 1 Mrs E V Aug 18 1953 This film demonstrates a small amount of fluid in each pleural space, with questionable enlargement of the right hilar shadow and some congestive changes in both lungs

Fig 2 —Case 1 Mrs E V Aug 18 1953 Right lateral film A marked senile kyphosis is noted with some pulmonary emphysema and again the small pleural effusion and passive congestive changes in the lung

Examinations of sputum and pleural fluid were negative for tumor cells Indirect laryngoscopy and bronchoscopy were essentially normal except for slight edema of the mucosa of the right middle and lower lobe orifices, but no secretions were present on either side The patient was slightly orthopneic before bronchoscopy so the procedure was done in the sitting position The bronchoscopic sputum likewise was negative for tumor cells

A complete blood count was within the range of normal limits and the urinalysis was normal The VDRL test was negative

On Aug. 10, 1953, a left supraclavicular biopsy was performed under 1 per cent Novocain infiltration anesthesia. A two-inch incision was made over the sternocleidomastoid muscle on the left horizontally, midway between the mandible and the clavicle. By blunt dissection the mass underneath the sternocleidomastoid muscle was explored and there was noted a complete thrombosis of the internal jugular vein. The vein was larger than normal and very succulent but firm. It was aspirated with a small gauge needle but no free blood could be found in it. By following the vein downward, it was apparent that the thrombosis extended to the junction of the internal jugular and subclavian veins. We considered ligating the vein to prevent emboli but this was not done as we feared it might pinch off another blood clot. It was suggested that, if ligation were to be done, it probably should be performed at the lowest portion of the internal jugular vein, with the patient under general anesthesia. No biopsy was taken. The incision was closed with interrupted subcuticular sutures of No. 000 chromic catgut. The postoperative condition was good.

Dr. W. W. Taylor saw this patient in consultation with us and the final diagnosis was congestive heart failure with complete thrombosis of the internal jugular vein. She was put on appropriate cardiac medical therapy. Inasmuch as she had had some thrombophlebitis *in the legs* previously, we considered her to have a migratory thrombophlebitis. If any future embolic episodes occurred, it was suggested that anticoagulant therapy be started. The patient was discharged from the hospital on Aug. 18, 1953, somewhat improved clinically.

Posteroanterior and lateral chest films made Aug. 18, 1953, showed a bilateral pleural *effusion*. The heart was obscured by the pleural effusion to a great extent and therefore the cardiac size could not be accurately determined. There was considerable kyphosis of the dorsal spine. There were some calcific plaques in the aortic arch. Films made a week later showed a decrease in the pleural effusion, bilaterally, but congestive changes were noted in both lung fields.

Comment.—This patient had a complete thrombosis of the internal jugular vein, with congestive heart failure, and a migratory type of thrombophlebitis.

CASE 2.—Mr. J. C. was a white man, 61 years of age. This patient was seen in consultation with Dr. Arthur W. Green at St. Joseph Hospital, Memphis, Tenn., on Nov. 10, 1953. He gave a history of an injury to the back and right shoulder, due to a fall sustained six or seven years previously. During the past several years, he had noted a drawing sensation in the neck on the right side. Two or three years before the neck had become sore and stiff but eventually this had disappeared almost completely. Two weeks prior to admission to the hospital the neck condition had flared up again with swelling and extreme tenderness. He had noted some earache. He had a dry, hacking cough with very little sputum. His weight was fairly stationary at 135 pounds. He stated he had had headache all the preceding summer and some weakness in the legs also. He had had several spells during which he felt faint but had never completely lost consciousness. His customers, however, had remarked on how poorly he looked at such times. Two weeks before admission to the hospital he had noted a rattling in his throat. He reported having colds of a persistent nature every winter.

Physical examination revealed a well developed, well nourished white man, who did not appear acutely ill. There was a diffuse mild tenderness and slight spasm over the right sternocleidomastoid muscle. No well defined mass was palpated. No supraclavicular nodes were demonstrated. The remainder of the physical examination was essentially negative except for a slight watchglass fingernail tendency.

X-ray films of the chest showed a ground glass appearance in the upper portion of the lung fields which was more extensive on the right side. There appeared to be a tumor in the right hilar area beneath the mediastinal pleura, which was homogeneous in density with the mediastinal shadow. On the lateral film this tumor was *midway* between the anterior and posterior walls. Our first impression was that this was a "mediastinal tumor of undetermined origin."

On Nov. 11, 1953, a right supraclavicular biopsy was performed, using 1 per cent Novocain infiltration anesthesia. A portion of the sternocleidomastoid muscle was removed for biopsy No *enlarged* lymph nodes were found but two or three nodes were removed for study The internal jugular vein was identified and was found to be completely thrombosed, and slightly enlarged The wound was closed and a cyst on the back, which contained some calcification, was then removed.

The pathologic report was "sections of the muscles show well developed bundles of striated muscle There is a minimal focal, chronic inflammatory cell reaction The blood vessels are not remarkable There is no evidence of collagen disease Cervical nodes show no tumor "

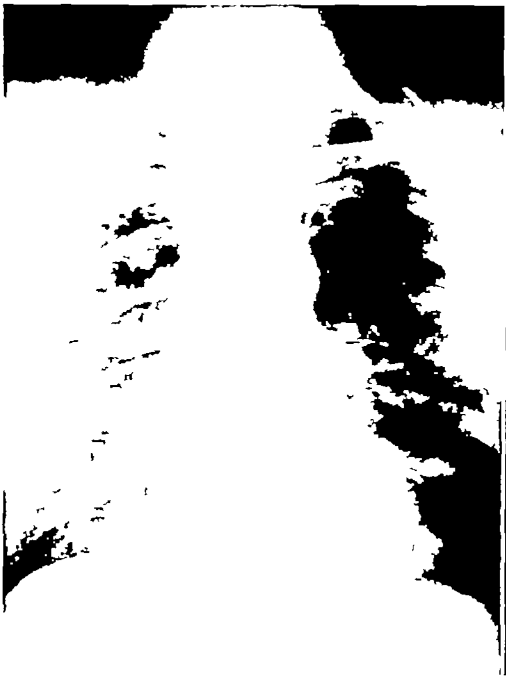

Fig 3

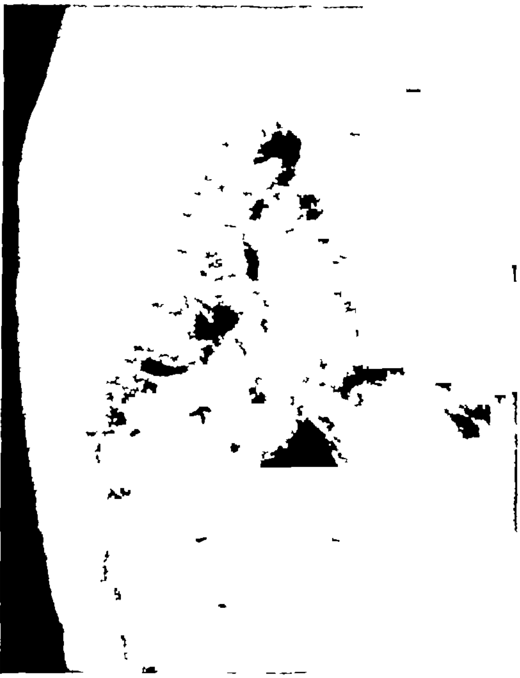

Fig 4

Fig 3—Case 2 Mr J C Nov 9 1953 There appears to be a tumor in the right hilar area beneath the mediastinal pleura This shadow is homogenous in density with the mediastinal shadow There is a ground glass appearance over the upper portion of the right lung field and to a lesser extent over the upper half on the left

Fig 4—Case 2 Mr J C Nov 10 1953 Right lateral film demonstrates the tumor to be located midway between the anterior and posterior chest wall in the hilar area There is also some infiltration in the right middle lobe area

Bronchoscopy and an indirect laryngoscopy were performed on Dec 15, 1953 There was considerable purulent sputum bilaterally, chiefly on the right side There was approximately a 25 per cent narrowing of the right main bronchial orifice with some redness in this location The remainder of the examination was essentially negative Secretions from the right main bronchus were negative for tumor cells Several expectorated specimens of sputum were negative also for tumor cells On cultures, the sputum contained no tubercle bacilli or fungi, but rare gram positive cocci were obtained

The electrocardiogram was normal, as was the urinalysis The blood albumin globulin ratio was normal The hemoglobin was 10 5 Gm red blood count 4 5 million white count 11 850 A sternal puncture was done Dec 29, 1953, and resulting paraffin sections were negative for Hodgkin's disease Although no definite pathologic diagnosis had been established clinically we felt that the patient had a bronchiogenic carcinoma with complete thrombosis of the right internal jugular vein He was given 40 mg of Mustargen intravenously in divided doses and discharged from the hospital He apparently did well for two months He was next heard from on Feb 20, 1954, at which time he was admitted to the Kennedy Veterans Hospital in Memphis On admission, he was in extremis and the admitting diagnosis was terminal bronchiogenic carcinoma of the lung with superior vena caval obstructive syndrome The history obtained from the relatives was that the patient had tolerated the chest and neck pain much better and had improved clinically following the nitrogen mustard therapy until a few days before admission to Kennedy Veterans Hospital Three weeks prior to admission to that hospital, he had developed a bilateral thrombophlebitis of the lower extremities which was still present on the right side at the time of admission Three days prior to admission he developed hemoptysis which had become more copious on the day of admission

On physical examination, he was moribund, with pulse of 120, blood pressure 97/60, temperature 97° F The skin was of a lemon color There was some residual edema of the orbital tissues over the face upper thorax, and upper extremities but no cyanosis Pedal edema was present There was subcutaneous edema of the thorax, upper extremities, face, and neck Impaired tactile fremitus was noted over the right base with breath sounds absent in that location Above this area was a definite expiratory wheeze Râles were present in both bases The heart tones were distant The liver was enlarged, four fingerbreadths below the costal margin No lymphadenopathy was present The abdomen was essentially negative The chest film showed considerable mediastinal lymphadenopathy with a pleural effusion at the right base and scattered parenchymal infiltrations compatible with an extensive bronchiogenic carcinoma The white count was 19,800, with 10 6 Gm of hemoglobin, red blood count 2 9 million and the urinalysis was normal The patient died on Feb 22, 1954, at 2 20 P M and an autopsy was performed The pertinent findings from this examination were as follows

Jugular Vein and Thoracic Duct—Sections from the thrombosed area in the jugular vein and from the wall of the jugular vein high up showed only thrombus material occluding this structure The thrombus material was attached to the wall and had partially recanalized Most of the thrombus was organized As one came down toward the junction with the innominate vein, however, definite tumor appeared in the vein and blocked the entire opening of the thoracic duct into the jugular vein The thoracic duct was greatly dilated and completely filled with tumor

The Final Anatomical Diagnosis—1 Bronchiogenic carcinoma, right, with metastases to the left lung, adrenals kidneys and left rectus muscle and direct extension to the mediastinum with involvement of the superior vena cava and the thoracic duct Metastases also were present in the heart 2 Thrombosed internal jugular vein, secondary to the tumor There were metastases also in the jugular vein 3 Verrucas vegetations were present in the tricuspid valve and the right ventricular cavity

Comment—This second case was a bronchiogenic carcinoma which had extended, causing complete thrombosis of the internal jugular vein

CONCLUSIONS

Intrathoracic disease can cause thrombosis of the internal jugular vein, the most common of these diseases being bronchiogenic carcinoma To the surgeon this possibility is very important and he should keep it in mind whenever he is performing a supraclavicular biopsy Two illustrative cases are included

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function normally as the coronary arteries were normally perfused Thus, through the open auricle or through the open ventricle it was easy to follow the movements At systole the valves join together like two half parachutes, to use the expression of Harken For the moment, it is of little importance

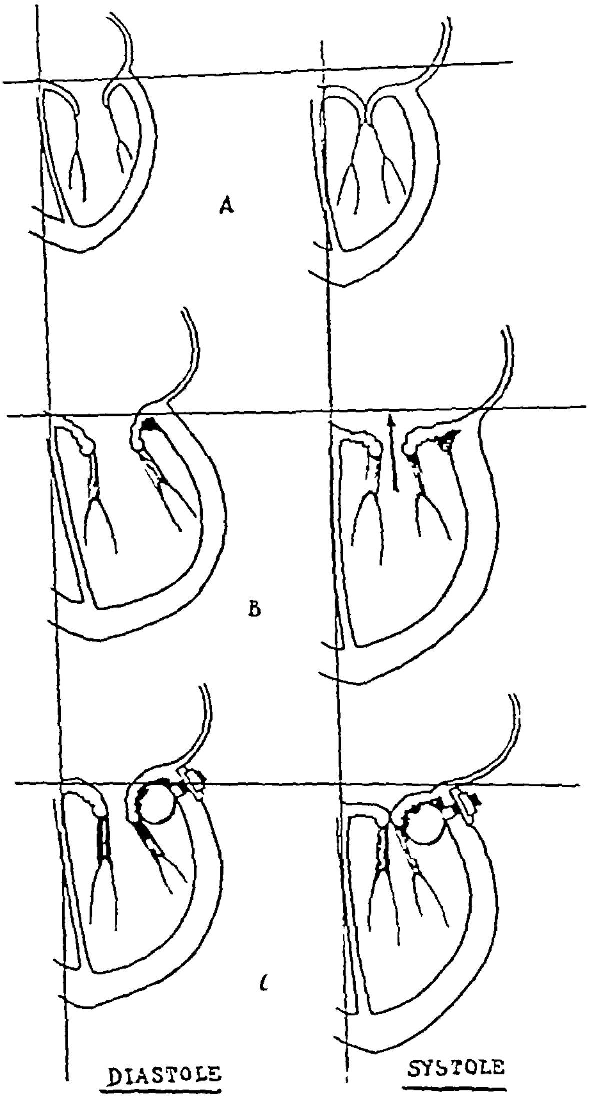

Fig 1—1 A Normal mitral valves B Mitral regurgitation C Mitral regurgitation corrected by our prosthesis Note the lowering of the mitral ring and the ventricular contraction [illegible] the systole

that they cover each other or that they free each other under the systolic flow of blood This unfolding of the valves is further increased by the lowering of the mitral ring and by the ventricular contraction during the systole The Chordae tendineae slacken at this moment so as to contract at the diastole The

Experiments on animals should be able to prove the efficiency of one of these operations. Unfortunately any experimental mitral insufficiency in animals can compare only roughly with that in human beings. In a dog one can produce the latter only by means of a serious valvular injury, which is exceptional in the human being. The rupture of a valve is severe and often fatal due to the sudden hemodynamic disturbance which it produces. Nor is it accompanied by any of the valvular and tendinous retractions which one usually finds in rheumatic endocarditis. Thus animal experiments are inexact and very difficult to evaluate for the survival of the dog is rare. Therefore the efficiency of any surgical treatment for mitral insufficiency must be judged by operations on man. Unfortunately it is difficult to arrive at a conclusion at the present time. The statistics already published are incomplete and are too cautious about the causes of death and about the condition of the patients who have survived the operation.

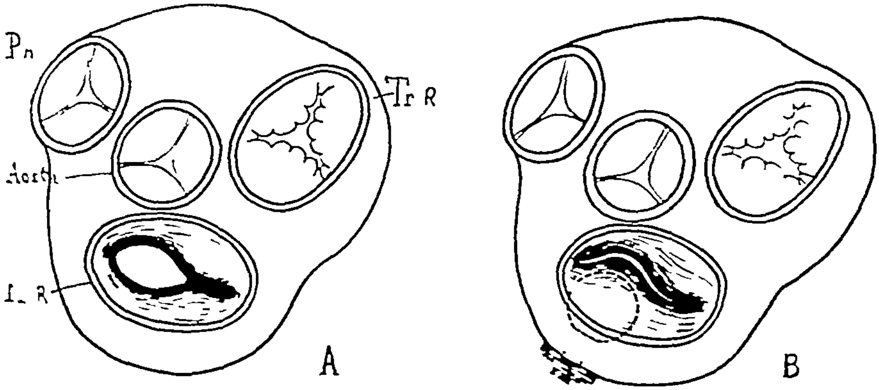

Fig. 1.—A view into the atrioventricular rings in a heart in which the atria have been removed. P A pulmonary artery and valves. T R tricuspid ring. M R mitral ring. A Shows a combined mitral stenosis and insufficiency. B Shows commissurotomy and correction of the insufficiency by our prosthesis.

THE OPERATION OF GORDON MURRAY

Our research on the surgical treatment of mitral insufficiency started in 1951. At first we experimented with a variation of the method of Gordon Murray using a transventricular pericardium flap.

Our results confirmed those of former research workers. It consisted of a benign operation well withstood. After opening the thorax and pericardium one cuts from the latter a pedunculated strip. It is then sewed in a finger shape 5 cm by 1 cm. A Reverdin curved needle is used to cross the left ventricle perpendicularly and pick up the end of the pericardial flap and introduce it into the ventricular cavity. One can either attach this end to the opposite ventricular wall or leave it free.

To be efficient this strip theoretically should be set on an axis perpendicular to that of the normal mitral orifice. But for obvious anatomical reasons already detailed by Brock and shown on a schema (Fig. 2) the strip can be [illegible] parallel to the axis of the mitral opening. In fact this pericardial strip regurgitation is thus a defect in the coming together of the two valves of the valvular parachutes. The valves and the chordae tendineae are shrunken, the mitral ring widened, and the left ventricle augmented in volume (Fig. 1).

THE GENERAL CONDITIONS OF A SURGICAL CORRECTION

Any surgical treatment of mitral insufficiency is a question of choosing among several possibilities: (a) a direct attack on the insufficient valves involving an actual valvuloplasty (Bailey[9]), (b) the placing of a prosthesis to fill in the gap in the mitral orifice (Harken,[10] our method[12, 14]), and (c) a search for a means of shortening the mitral ring (Glover[11]).

But above all, any treatment of mitral insufficiency must obey the following rules:

1. The operation must be simple and speedy. In a condition as grave as this, the patient could not endure long and complicated techniques. This eliminates, at least for the present, surgery with the open heart using the artificial heart-lung. Surgery by means of hypothermia allows only a few minutes of work, which is insufficient for lesions so complex.

2. The operation must not cause thrombosis. Rheumatic endocarditis can of itself be a cause of thrombosis and emboli. But the slightest foreign body in the heart, above all, if it is in the midst of the blood flow, can induce it. In particular, one must absolutely avoid any foreign body in the left auricle which is the usual site of thrombosis. The material of the foreign body is also important. Fragments of tendon, strips of pericardium, segments of turned back vein, and plastic prostheses have been used inside the left ventricle. We think that the plastic prostheses are the least likely to produce thrombosis. But the perfect fixation of the foreign body to the myocardium seems to be the most important factor of tolerance. Take, for example, a prosthesis that we will describe further on. When this prosthesis is not completely bound to the myocardium, the contraction of the ventricle and the blood flow communicate to it a rhythmical movement comparable to that of the movement of a bell. This churning of the blood causes a thrombosis.

3. The foreign body must be sufficiently fixed so as not to embolize. The prosthesis, itself, must be solid and in one piece, to avoid all risk of breakage.

4. Last, it is necessary that by its volume, the element of repair, thread, or prosthesis should not diminish *in any way the volume of the left ventricle.*

Having defined the conditions for an operation which will not be dangerous, we are obviously limited as how to meet the demands of an efficient correction for mitral insufficiency. The rigidity and insufficiency of the mitral opening are due to the lessening of the surface and mobility of the valves. The retraction of the chordae tendineae and the enlargement of the muscular mitral ring make the wide-mouthed orifice still larger. Will it be sufficient to bring together the two borders of the valves to do away with the regurgitation as Bailey practices it? Ought one to prefer the tightening of the muscular ring as Glover suggests? What are the reasons for choosing an intracardiac prosthesis to make up for the valvular insufficiency, and how is one to choose between all those that have been tried?

Experiments on animals should be able to prove the efficiency of one of these operations Unfortunately any experimental mitral insufficiency in animals can compare only roughly with that in human beings In a dog one can produce the latter only by means of a serious valvular injury, which is exceptional in the human being The rupture of a valve is severe and often fatal due to the sudden hemodynamic disturbance which it produces Nor is it accompanied by any of the valvular and tendinous retractions which one usually finds in rheumatic endocarditis Thus animal experiments are inexact and very difficult to evaluate for the survival of the dog is rare Therefore the efficiency of any surgical treatment for mitral insufficiency must be judged by operations on man Unfortunately it is difficult to arrive at a conclusion at the present time The statistics already published are incomplete and are too cautious about the causes of death and about the condition of the patients who have survived the operation

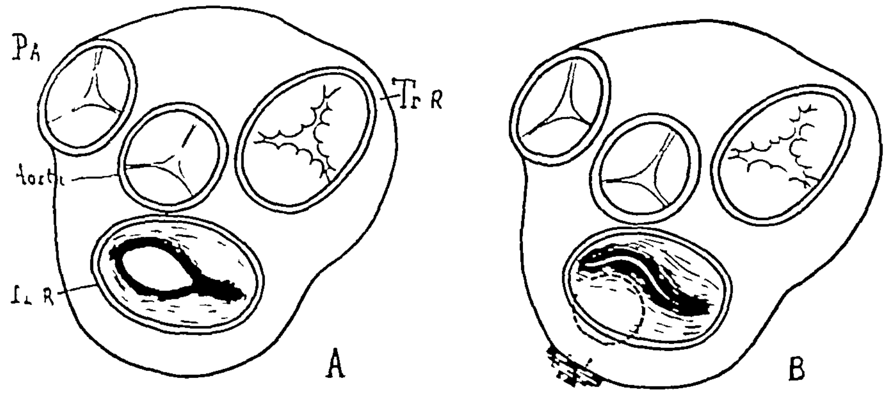

Fig 1 —A view into the atrioventricular rings in a heart in which the atria have been removed *P A* pulmonary artery and valves *T R* tricuspid ring *M R* mitral ring *A* Shows a combined mitral stenosis and insufficiency *B* Shows commissurotomy and correction of the insufficiency by our prosthesis

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To be efficient this strip theoretically should be set on an axis perpendicular to that of the normal mitral orifice But for obvious anatomical reasons already detailed by Brock and shown on a schema (Fig 2) the strip can be only parallel to the axis of the mitral opening In fact this pericardial strip always scleroses and thus loses any value We have been able to verify this on a group of three dogs, which when sacrificed, 75, 105 days, and more than 1 year after the operations, all showed the same sclerosis of the flap Therefore, we planned a prosthetic intracardial piece to be fixed against the myocardium, under the posterolateral valve

DESCRIPTION OF OUR METHOD

Since 1951, we have been searching for the ideal form for this prosthesis[1 14] We have used different types of lens and, also, sword-shaped pieces in plastic Finally, we have chosen spherical balls, perfectly smooth At first, the ball was fastened by a steel wire, passed through the ball, whose two ends, after passing through the myocardium, could be drawn taut and tied on the outside But experience proved that these wires broke quickly, therefore, we use a rigid type (Fig 3) It is composed of a sphere, whose diameter depends on the size of the mitral ring and the heart volume The sphere has on one side of it a shank threaded along all its circumference, except for 2 symmetrical flat sides These 2 flat sides act as a surface for a counterscrew which cannot turn to glide along the shank Another screw is fastened on the shank, this screw fits into an opening cut out of the outer side of the counterscrew As soon as the screw is placed in the counterscrew, it is firmly held by a lock-nut principle The balls we have used had a diameter of 10 to 15 mm We have used shanks 25 mm long, ending in an eyelet hole, through which a draw thread can be put

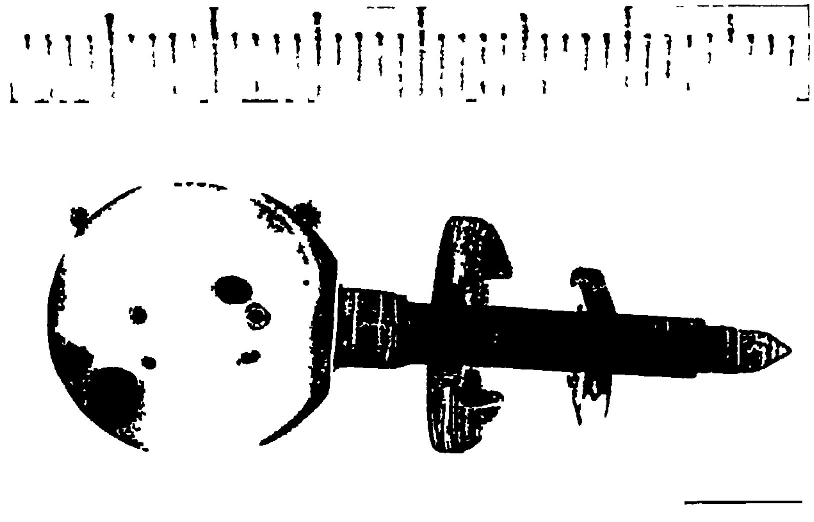

Fig 3 —The ball we are using Note in the middle of the figure the counterscrew which glides along the shank and at the right end the screw which is fastened on the shank

Access to the heart and more especially to the left ventricle is made by an anterolateral thoracotomy as low as the level of the seventh intercostal

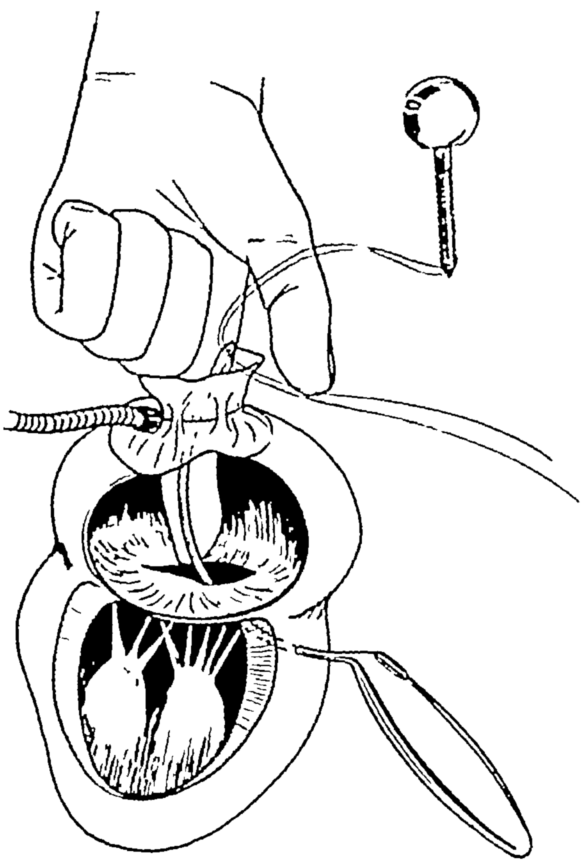

Fig 4

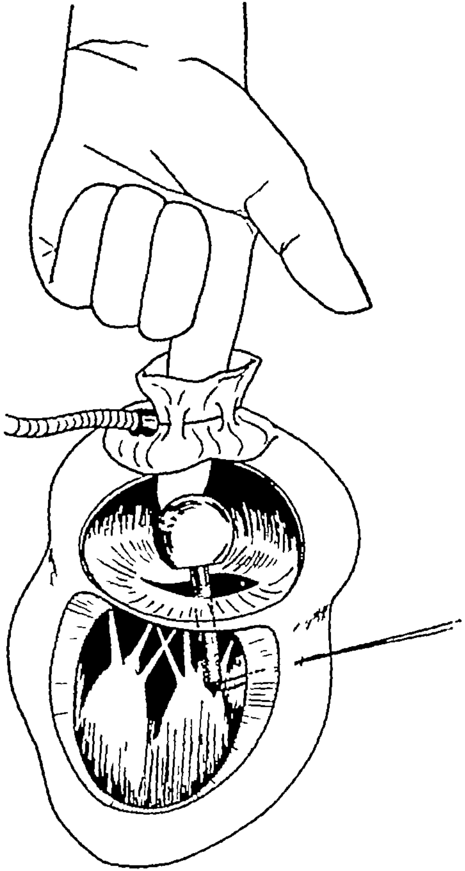

Fig 5

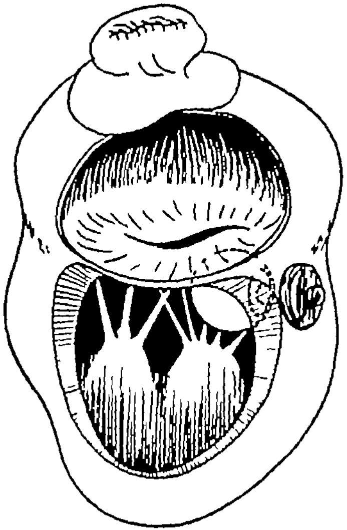

Fig 6

Fig 4 —The index finger introduced in the auricle conducts a blunt ended Reverdin's needle
Fig 5 —The index finger pushes the ball toward the ventricle
Fig 6 —The ball in place Note its position under the posterolateral valve and the fixation by the lock nut system

space One must be able to approach the posterolateral surface of the left ventricle which is adjacent to the diaphragm The pericardium is opened by a longitudinal incision, parallel to the phrenic nerve Opening of the auricle and mitral exploration are done in the usual manner The latter, however, is the guide in the choice of the size of the ball and of its position under the posterolateral valve With the index finger always in the auricle a blunt ended Reverdin's needle is introduced into the ventricle (Fig 4) The point of approach must be clearly known, it is situated immediately behind the circumflex artery, a branch of the auriculoventricular artery, 2 fingerbreadths under the auriculoventricular groove, in other words, in the part most posterior to the ventricle The needle pierces the ventricle rapidly and then enters the atrium It comes out along the index finger One quickly passes a thread which secures the ball by the end of its shank The needle is then withdrawn through the myocardium The index finger is then removed from the auricle, which is clamped Following this, it is easy with a little experience to pass the ball quickly into the auricle, without any appreciable loss of blood The finger follows the ball which, pushed from one side, drawn by the transmyocardial thread from the other, is to be fixed in the required corner (Fig 5) Then all that is necessary is to slide the counterscrew, to fasten the screw, and to cut the obtruding part of the shaft (Fig 6) After another verification by the mitral finger, the auricle, the pericardium, and the thorax can be closed The operation is simple and does not entail much loss of blood It should last not more than one and one-half hours

MATERIAL AND RESULTS

Thirty seven healthy, adult mongrel dogs weighing from 10 to 30 kilograms were used for this experiment

In a first group, we operated on five dogs using different types of prostheses On one dog, a ball fixed to the myocardium by a nylon hammock rapidly embolized To lessen mobility of the ball, we put a steel wire through it The two extremities of the wire after passing into the myocardium were tied outside on a small plastic button On other dogs, a spherical ball was used three times and a sword-shaped piece just once After these operations, three dogs died within 24 hours Another died of endocarditis on the twenty fourth day as a result of the beating of the insufficiently fixed ball Last, a fifth dog had to be sacrificed on the fortieth day The ball had been secured by two wires and only one was found intact We, also, found that the prosthesis was firmly enclosed under the posteroexternal valve and covered by a sheet of fibrous tissue continuous with the endocardium around it

We gave up this method of maintaining the prosthesis because (a) the fixation was insufficient (b) the fixing wires broke almost every time

In our second group we used the Plexiglass ball with threaded shank The operative technique used was that set out and described at the beginning of this paper

In twenty-two operations on dogs

- 10 died within 12 days following the operation
- 1 died on the thirtieth day
- 6 were sacrificed between 2 to 3 months after
- 3 were sacrificed between 5 to nine months after
- 1 was sacrificed after 22 months
- 1 is living after more than 23 months

The causes of death were

- 2 due to pleural empyema
- 3 due to operative hemorrhage or anoxemia, and
- 6 due to thrombosis and emboli resulting from malposition of the ball

The eleven dogs that died were among the first thirteen operated on in this group while we were looking for a good technique The most frequent cause of death was embolus coming from the thrombosed areas around the prosthesis In all these cases the prosthesis had been incorrectly placed in three dogs, the ball was found to be in the atrium, its shaft piercing the small valve and in three other dogs the screw had been insufficiently tightened and the ball was loose in the ventricle We think that these malpositions were the cause of thrombosis and emboli Since we have succeeded in placing and fixing the balls correctly, these complications have disappeared

The study of the eleven surviving animals has shown an excellent tolerance After the postoperative period they have lived normal lives among the others in a big kennel All the animals save one were sacrificed at different periods between 2 and 22 months The animal examined 22 months after the operation was one which 8 months after the operation, had whelped a big litter One dog 23 months afterward is living and in good health

Our examinations have shown that the heart has never increased in size Externally there was no evidence of the operation except for a slight pericarditis thickened a little at the point of the lock nut The cardiac cavities have never revealed signs of thrombosis The prosthesis was in good position under the posterolateral valve Each time it was seen to be covered by tissue which to the naked eye was a complete continuation of the adjacent endocardium (Fig 7) Microscopic examination showed this covering to have all the histological characteristics of the endocardium (Fig 8)

Our third group consisted of ten dogs The aim was to create a mitral insufficiency and then to correct it by means of our prosthesis We showed earlier that any such insufficiency produced artificially can simulate only poorly the patterns of that found in human beings while on the other hand it increases hemodynamic disturbances

We operated in the following manner By means of two polythene catheters introduced into a left pulmonary vein the pressures of the auricle and left ventricle were registered simultaneously One of these catheters led to the atrium and the other to the left ventricle

It is more difficult than one believes to destroy a mitral valve in a normal animal In any case the finger can do little damage to the cords and valves

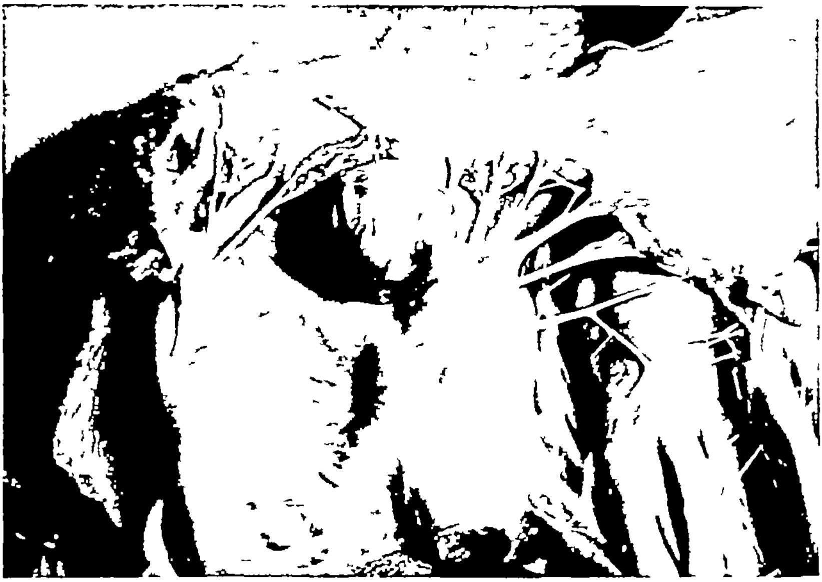

Fig. 7.—The heart of a dog sacrificed twenty months after the operation. The prosthesis is covered by a tissue in complete continuation with the adjacent endocardium.

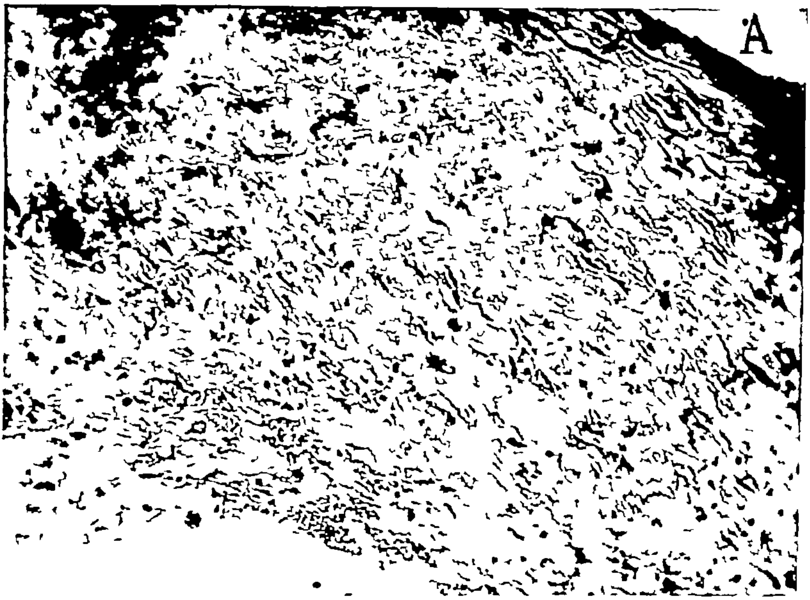

Fig. 8.—Microscopic section of the tissue covering the prosthesis twenty months after operation (same animal as in Fig. 7). *A*, The cardiac lumen. All the structure of an endocardium is reproduced.

We devised a special valvulotome in the form of a scythe. The index finger holding this valvulotome was introduced into the left auricle, and cut the insertions of the posterolateral valve in whole or in part. It is difficult to proportion the lesions. One can estimate them only after observing the hemodynamic alterations. At this point of the operation, hemostasis of the auricle is harder to accomplish. The blood jet is markedly more forcible. The pressure in the auricle is considerably raised and lowered in the ventricle. Mitral regurgitation is evident and if it is not immediately corrected, death is almost instantaneous.

When our prosthesis is fixed the clinical and hemodynamic signs disappear immediately. Auricular hemostasis becomes easier and the force of the pulsations of the auricle lessens. Left auricular pressure though considerably lowered does not reach the normal preoperative level registered. This fall in auricular pressure results in a slight rise in systolic pressure and a diminution in diastolic pressure in the ventricle. One can see this in Fig. 9.

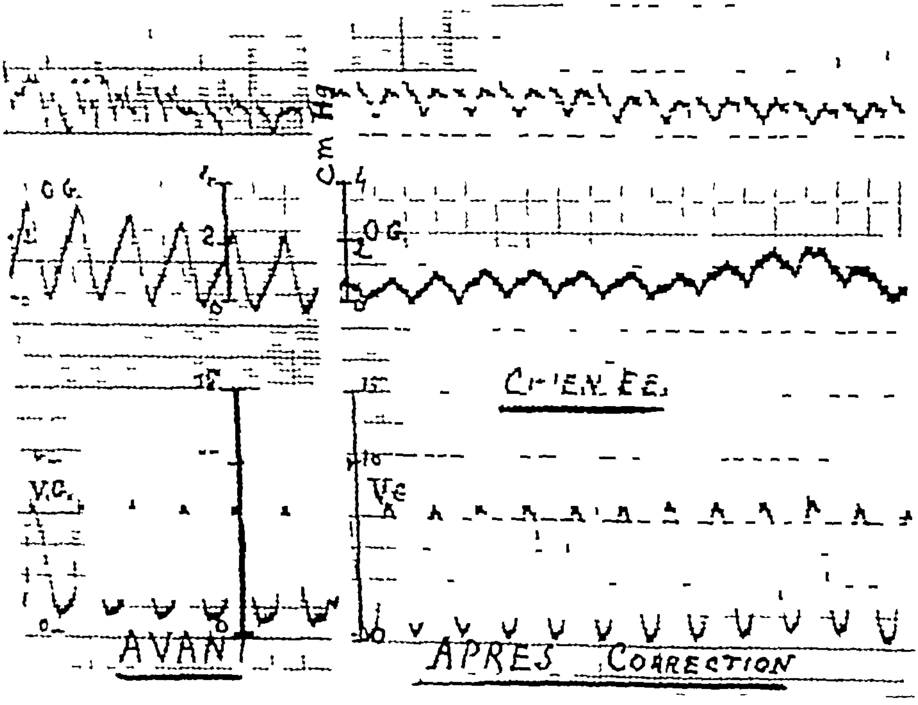

Fig. 9.—A, The left auricular and left ventricular pressure curves of a dog with an experimental mitral insufficiency. OG, left auricle; VG, left auricle. The pressures are measured in centimeters of mercury.

B, The same pressure curves of the same dog after correction of the mitral regurgitation by [illegible]

DISCUSSION AND CONCLUSION

The conditions which have led us to use our prosthesis were the following: (1) to use a round and smooth prosthesis, (2) to fix it under the posterolateral valve by a threaded transventricular rod blocked by a lock nut system and (3) to [illegible] by the ventricular contraction toward the septum at systolic closing of the mitral orifice.

We have endeavored to determine the tolerance of our prosthesis. First we have attempted to avoid the production of any intracardiac thrombosis. In practice, any ball badly gauged for the mitral orifice, inadequately fixed, or in a wrong place, results in a thrombosis, always fatal This, in our opinion explains the failure of any mobile prosthesis in the ventricle Following the operative technique described, the ball is put into position in less than an hour The immediate postoperative progress is uneventful The later results were studied after an interval of 23 months Clinically, the prosthesis has been well tolerated All the animals have lived normally among the others Microscopically, the tolerance of the ball is proved by the covering of vascular connective tissue which incorporates it in the myocardium This covering develops as early as the second month Thus, the prosthesis quickly loses the characteristics of a foreign body, and becomes a natural element of the myocardium It acts as a shelf support holding up the posterolateral valve and, in addition by its volume, it partly occludes the area of regurgitation

Our theoretical ideas on the value of the prosthesis had to be verified by experiment We have been able to create a mitral insufficiency in a certain number of animals Immediately afterward, during the same operation, introduction of our prosthesis has caused the disappearance of all the hemodynamic signs of regurgitation No dog of the last group survived, death being caused by shock and, above all, by hemorrhage due to the creation of the mitral insufficiency and the use of heparin for a continuous pressure reading

Thus, we believe that we have shown our prosthesis to be well tolerated by the heart and efficient for the correction of mitral insufficiency Hence, its use on man is indicated We will give the results in a later report

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INTRADIAPHRAGMATIC CYSTS

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INTRADIAPHRAGMATIC cysts are rare and their preoperative diagnosis is uncertain. In recent surgical literature we found only seven cases of cysts within the diaphragm.[1-6] To these we add an intradiaphragmatic bronchogenic cyst. These eight cases include only those cysts which seemed to be actually within the musculature of the diaphragm. Cysts attached or lying adjacent to the diaphragm are much more common and are not discussed here, although embryologically related to the intradiaphragmatic cysts.[7-10]

CASE REPORT

A 41 year old white woman was hospitalized because roentgenograms of the chest had revealed a mass in the region of the left leaf of the diaphragm. She was essentially asymptomatic although she had a slight dry cough. Chest roentgenograms had been taken two years and one year previously. Originally these films had been read as negative but on reexamination showed the same oval area of increased density overshadowed by the cardiac silhouette (Fig. 1). Only a slight increase in size had occurred in a two year period. Roentgenoscopy indicated that the lesion moved with the diaphragm and distorted slightly the adjacent diaphragmatic contour in some phases of respiration. Roentgenogram of the chest in the right lateral recumbent position suggested that there was a slight alteration in the shape of the lesion with change in position. This film had been taken to determine whether the mass extended below the diaphragm but overlying densities obscured the lower portion of the lesion. A diagnosis of possible cystic lesion in or near the diaphragm was made.

An exploratory operation was performed in the lateral position through the left eighth interspace. The pleural cavity was free of adhesions and fluid. The lung was normal. In the posterolateral portion of the diaphragm a localized elevation of the diaphragm, which at first glance suggested partial eventration, was noted. Incision in the overlying diaphragmatic pleura exposed a large multiloculated cyst within the musculature of the diaphragm and intimately associated with it. The inferior aspect of the cyst extended toward the peritoneum. The major portion of the cyst was directed toward the pleural cavity. The blood supply consisted of a 4 mm artery apparently arising directly from the [illegible]. The artery was accompanied by a vein at the medial aspect of the cyst. These vessels were ligated and the cyst easily excised without penetrating the peritoneum. The postoperative course was uneventful.

Pathologic examination revealed a 9 by 7 by 7.5 cm multiloculated thick walled cyst containing [illegible] watery material. Microscopic examination showed that the cyst was lined by ciliated columnar epithelium supported by a loose connective [illegible]. Intimately associated with the smooth muscle of the cyst [illegible] of the diaphragm. The diagnosis was bronchogenic cyst.

PATHOLOGY

The eight intradiaphragmatic cysts reported fell into three groups (Table 1). There were three cases of mesothelial cyst, two bronchogenic

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[illegible]

[illegible]

TABLE I

AUTHOR	HISTORY	LOCATION	SPECIAL DIAGNOSTIC STUDIES	OPERATION	FINDINGS	PATHOLOGY
Robson and Collis[1]	22 year old man Low chest pain	Right diaphragm in posterior costophrenic angle	Casoni test negative, pneumothorax failed because of obliterative pleuritis	Thoracotomy and excision	Thick walled cyst containing granulations, partially calcified	Cyst of doubtful etiology, probably tuberculous
Scott and Morton[2]	29 year old man Chest pain, nonproductive cough, dyspnea	Left diaphragm in dome	Casoni test negative	Exploratory laparotomy, splenectomy, excision of cyst	Thick walled trabeculated cyst containing chocolate colored fluid, partially calcified	Primary cyst of diaphragm, origin undetermined, lined with single layer cuboidal epithelium
Nylander and Vikari[3]	17 year old male Persistent abdominal pain following appendectomy	Right cardiophrenic angle	Pneumothorax	Thoracotomy and excision	Thick walled cyst containing clear fluid	Mesothelial cyst
Clagett and Johnson[4]	39 year old woman Asymptomatic, lesion found on survey	Left diaphragm anterior axillary line		Thoracotomy and excision	Thick walled fibrous cyst containing puttylike material	Fibrous walled cyst
Cruickshank and Cruickshank[5]	11 year old man Asymptomatic, lesion found on survey	Right diaphragm near cardiophrenic angle	Pneumoperitoneum	Thoracotomy and excision	Thin walled bluish cyst	Mesothelial cyst low cuboidal epithelium
Cruickshank and Cruickshank[5]	49 year old woman Slight exertional dyspnea	Left diaphragm near cardiophrenic angle		Thoracotomy and excision	Thin walled bluish cyst	Mesothelial cyst, low cuboidal epithelium
Bolivar[6]	45 year old man Right lumbar pain	Right diaphragm	Retrograde pyelogram, retroperitoneal oxygen insufflation	Thoracotomy and excision	Multiloculated cyst containing clear white substance	Bronchogenic cyst lined by ciliated columnar epithelium
Kessler and Maier	11 year old woman Dry cough	Left diaphragm	Left lateral recumbent radiographs of chest	Thoracotomy and excision	Multiloculated cyst containing tan opalescent substance	Bronchogenic cyst lined by ciliated columnar epithelium

cysts, and the third group consisted of three cases of a thick-walled fibrous cystic lesion of uncertain origin as described by Scott and Morton,[2] Clagett and Johnson,[4] and Robson and Collis.[1] The first two groups represent forms of embryonic sequestration of mesothelial or pulmonary elements which have lost continuity with their parent tissue.

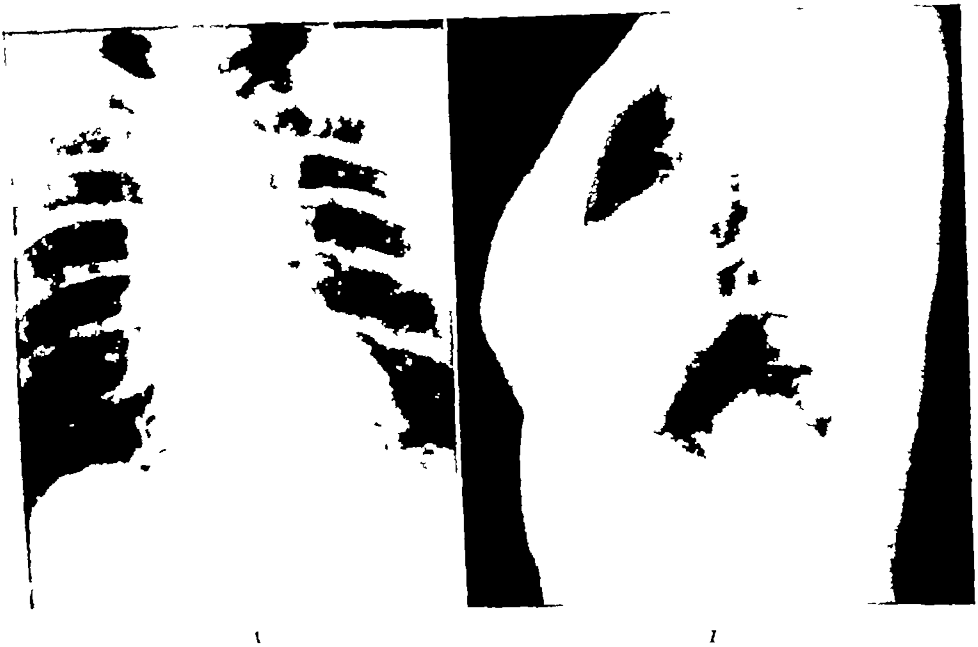

FIG. 1.—A. Posteroanterior roentgenogram with arrows indicating an oval shadow of increased density partly obscured by the cardiac silhouette. Note the relationship to the diaphragm.

B. Left lateral projection shows the mass to be posterior. The outline of both leaves of the diaphragm appears separate from the mass. This film did not suggest that the cyst was intradiaphragmatic.

The mesothelial cysts were described by Nylander and Viikari[7] and Cruickshank and Cruickshank. The latter authors ascribe the development of such cysts as resulting from the pinching off of the advancing edges of the septum transversum, the pleuropericardial and the pleuroperitoneal membranes as they grow toward each other and fuse to form the diaphragm. Errors in the development of these three structures account for the increased incidence of cysts in and just above the diaphragm.[9, 10]

The second form of sequestration noted in this group of cases is the bronchogenic cyst. The widespread sites of bronchogenic cysts in the thorax have been discussed by Maier[11] in relation to their symptomatology and diagnosis. The vascular factors in the development of bronchogenic sequestrations have been described and their significance discussed by Pryce, Sellors and Blair and Bruwer, Clagett and McDonald.[3] It seems probable that the cysts seen in the mediastinum, diaphragm and upper abdomen represent an early embryological abnormality which develops because of the maintenance of the dorsal vascular anlage. According to Pryce[14] cells of the pulmonary ridge are held dorsally by these vessels as the main pulmonary cell mass grows ventrally and caudally. These cell nests thereby lose continuity with their parent tissue, retain their systemic blood supply, and develop independently in the mediastinum, diaphragm, or abdomen.[16, 17]

The origin of fibrous cysts without a characteristic lining is uncertain. It is difficult to ascertain whether such lesions are of congenital or acquired origin. Similar masses are occasionally encountered in the mediastinum.

DIAGNOSIS

The diagnosis of intradiaphragmatic cyst is usually made at operation rather than preoperatively since the cyst cannot easily be differentiated from a tumor mass. Primary neoplasms of the diaphragm are more common than cysts and their prognosis is more serious. In a recent review by Crimm and Kiechle,[18] 38 cases of primary tumor in the diaphragm were analyzed. Sixteen were benign and twenty-two were malignant tumors. In this collected series, about 58 per cent of the tumors primary in the diaphragm were sarcomas.

Other conditions which may enter into the differential diagnosis of a cyst in the diaphragm are basilar lung lesions, partial eventration of the diaphragm, cysts of the pericardium or pericardiophrenic angle, diaphragmatic hernias, tumors of the liver, echinococcus cysts, intramural tumors of the esophagus or cardia of the stomach, and neoplasms of the adrenal or kidney.

Symptoms associated with cysts in the diaphragm varied considerably and none are pathognomonic. Four of the cases were asymptomatic and represented chance findings on mass chest surveys. The other four cases had low chest or abdominal pain, shortness of breath, or a nonproductive cough.

Posteroanterior and lateral roentgenograms of the chest will usually demonstrate the lesion. Occasionally the cyst may be overlooked due to superimposition of the cardiac silhouette or because the density does not project sufficiently above the shadow of the diaphragm. The lateral recumbent roentgenogram may indicate a change in shape of the lesion suggestive of its cystic nature, or demonstrate an infradiaphragmatic projection. Roentgenoscopy and barium studies of the esophagus, stomach, and colon will assist in ruling out lesions of the esophagus, hiatus hernia, and herniation through the foramen of Morgagni. Sectional body roentgenograms will help distinguish lesions in the lung. Retrograde pyelography and retroperitoneal oxygen insufflation may be used when a question of suprarenal or renal origin of the lesion arises. Beck, Clough, and Brochu[19] recommended pneumoperitoneum to distinguish partial eventration of the diaphragm from tumor in the liver, herniations, or a lesion in the diaphragm. If a partial eventration of the diaphragm can be demonstrated, surgical exploration may not be necessary. If there is any calcification in the lesion, tuberculosis or echinococcus cyst must be considered. The Casoni intradermal skin test may help to rule out an echinococcus cyst.

TREATMENT

Although cysts of the diaphragm are usually not serious lesions, inability to differentiate them definitely from primary neoplasms of the diaphragm, which are not infrequently malignant, makes surgical intervention necessary. A low posterolateral thoracotomy approach is recommended. The surgeon must ascertain the nature of the intradiaphragmatic lesion in order to determine the method of excision. Removal of a cyst will not present the problem of diaphragmatic reconstruction posed by some connective tissue tumors of the diaphragm. In excision of a bronchogenic cyst, the surgeon should remember that the pedicle in the region of the aorta may contain an artery of fair size which should be carefully dissected out.

SUMMARY

Cysts within the diaphragm are rare and their diagnosis preoperatively is difficult. Most are discovered roentgenologically in a person with few or no symptoms. Surgical excision by the thoracic approach is usually recommended because the cyst cannot with certainty be differentiated from more serious lesions. A review of some surgically treated cases has been presented and a personal case of intradiaphragmatic bronchogenic cyst is reported. Mesothelial, bronchogenic, and thick-walled cysts of uncertain origin are apparently the most common types of cyst to be found within the diaphragm. Similar cysts are found more often merely attached to the diaphragm or located in adjacent areas.

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TRAUMATIC RUPTURE OF THE ESOPHAGUS

(With a Report of 13 Cases)

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TRAUMATIC rupture of the esophagus is a catastrophic accident which is increasing in frequency and one that is associated with prohibitive mortality and morbidity unless early diagnosis, vigorous resuscitation, and definitive surgical therapy are carried out. The pathologic anatomy of the lesion may vary considerably with the rupturing agent, whether it be by diagnostic or therapeutic endoscopy, an ingested foreign body, a penetrating missile, or by an intrinsic force engendered by the patient himself. The previous pathological state of the esophagus may also greatly influence the type of surgical therapy to be employed, i.e., drainage, a primary repair, or resection and anastomosis.

ETIOLOGY

With the increasing use of diagnostic and therapeutic endoscopy, it is not surprising that these procedures are the leading cause of traumatic rupture of the esophagus. Jemerin[5] reported more than a 100 per cent increase in traumatic esophageal ruptures following endoscopy at Mt. Sinai Hospital in the last decade in comparison with the previous decade. Seybold[10] reported 21 cases in the first thirty-six years of the Mayo Clinic, with an additional 29 cases during the years of 1943 through 1949. The Tulane Thoracic Surgery Service of the Charity Hospital in New Orleans saw in consultation and treated 9 cases of traumatic perforations of the esophagus from July, 1950, until June, 1953, and saw 4 other cases in consultation: one at the Charity Hospital in New Orleans and 3 cases at the H. P. Long Charity Hospital in Pineville, Louisiana. Nine of the cases to be reported here were produced during endoscopic manipulations by other services or outside physicians, 8 occurred in the Charity Hospital and one patient was referred to this hospital fifteen hours after an attempted removal of a chicken bone by bouginage. Four cases were perforations which involved the cervical esophagus and were produced by penetrating missiles. The increasing frequency of rupture seems to parallel the increasing frequency with which esophageal and gastric endoscopy is being performed. The endoscopic procedures that seem to be the most hazardous are dilatations for strictures and achalasia and the removal of foreign bodies.

Penetrating missile injury of the esophagus is relatively rare in civilian practice and when seen it is usually of the cervical esophagus, as is true in the cases reported here. The thoracic esophagus is so surrounded by vital structures that injury to the viscus is commonly associated with fatal injury to the heart or great vessels.

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Another form of traumatic rupture of the esophagus that is receiving considerable attention in recent literature (Anderson,[1] Barrett,[2] Carter,[4] Mackler,[7] Olsen,[8] and Samson[9]) is the so called "spontaneous" rupture of the esophagus Of 104 proved cases,[1] almost without exception the accident has followed prolonged or forceful emesis, usually the result of gluttony and less commonly in postoperative and self-induced vomiting

PATHOGENESIS

The occurrence of rupture from instrumentation is due to technical faults, an uncooperative patient, or severe disease of the esophagus, and is frequently due to a combination of these factors In 8 of the 9 cases reported here, local anesthesia was used for instrumentation, and in 3 of the cases, the patients were quite elderly being 78 79, and 88 years of age, respectively These factors may have added to the technical difficulties Rupture may occur at any level although the most common sites have been in the cervical esophagus immediately adjacent to the cricopharyngeus "sphincter," and at and immediately above the esophageal hiatus, as both sites are anatomical areas of fixation and narrowing of the esophagus In cervical esophageal ruptures during endoscopy, it is our feeling that the tear is produced in the fragile viscus by the rigid scope as unusual pressure is exerted to overcome the resistance of the cricopharyngeus muscle The scope becomes displaced during the maneuver causing a low hypopharyngeal rupture, or as the "sphincter" resistance is suddenly overcome the inflexible tube strikes the fixed posterior esophageal wall with considerable force and a perforation results In all 6 of our cases in which a primary repair of an endoscopic tear of the cervical esophagus was carried out, the rupture was on the posterior wall immediately adjacent to the cricopharyngeus muscle Five cases were below and 1 was above the cricopharyngeus It is apparent that in the manipulation of impacted foreign bodies, the hazard of esophageal perforation may be considerably increased It is our opinion that after a reasonable attempt has been made it is better to proceed with formal esophagotomy with removal of any foreign bodies under direct surgical vision rather than to persist in efforts at endoscopic removal

In dilatation for strictures and for achalasia considerable force must often be used to achieve an effective therapeutic result and in cases of advanced local pathology the hazard of rupture may be considerable In 600 cases of achalasia at the Mayo Clinic Olsen and associates[8] report 10 cases of rupture during treatment by dilatation

In considering the pathogenesis of "spontaneous rupture of the esophagus it has been shown that anatomically the inferior esophageal segment is the weakest area in the esophagus This is probably due to the spiral arrangement of the lower circular muscle fibers as they form the functional inferior esophageal sphincter as well as to the spreading out of the longitudinal muscle fibers as they extend to and become continuous with the middle and outer layer of the gastric musculature (Kay) It has been shown experimentally that the musculature ruptures first and that this is followed by a diverticulum-like protrusion of the mucosa which is the last to give way (Mackler[7]) In the course of repeated vomiting, esophageal obstruction may occur due either to an impacted bolus or to a functional obstruction caused by *incoordination* of relaxation throughout the esophagus brought on by fatigue, or to spasm caused by the action of the acid gastric juice as it is expelled In the face of such obstruction, either mechanical or functional, sufficiently high intraesophageal pressures must occasionally occur as to result in traumatic rupture of the organ

"Spontaneous" rupture occurs almost without exception immediately above the esophagogastric junction on the left posterolateral wall and appears as a linear slit, with eversion of the mucosa, in an otherwise normal-appearing esophagus Experimentally, the introduction of five pounds of air pressure into an esophagus with both orifices closed will cause an exactly similar lesion in 95 per cent of the cases (Mackler[7]) Wangensteen[11] believes that the underlying etiology is peptic esophagitis due to gastric regurgitation, but biopsies taken at operation have failed to substantiate this theory in many cases (Samson,[9] Mackler[7])

DIAGNOSIS

The diagnosis of traumatic rupture of the esophagus can be made without undue difficulty, regardless of the mechanism of rupture, if the likelihood of the accident is kept in mind At endoscopy, rupture is frequently not recognized as having occurred at the time and the endoscopist may be reluctant to accept such a possibility until the diagnosis is confirmed In only 2 of the 9 cases occurring at endoscopy, did the endoscopist recognize immediately that rupture had probably occurred

Rupture of the thoracic esophagus is commonly associated with a more fulminating onset and progression of symptoms than is the perforation of the cervical esophagus This fact is due to the immediate contamination of the mediastinal space which gives rise to progressive mediastinal emphysema and compression and is accompanied or followed shortly by involvement of the pleural space with effusion, collapse of the lung, and possibly signs of a tension pneumothorax A patient who complains of excruciating cervical or thoracic pain during or shortly after endoscopy, forceful vomiting, or a penetrating neck wound, followed by the appearance of respiratory distress, variable shock, dysphagia, and interstitial emphysema should strongly be suspected of having a ruptured esophagus Supportive therapy and confirmatory diagnostic procedures must be instituted immediately as an emergency Mackler[7] states, "a history of sudden thoracic pain occurring during or shortly after the act of vomiting followed by the appearance of interstitial emphysema at the base of the neck, constitutes sufficient evidence to warrant a left thoracotomy" If the rupture is at or adjacent to the esophageal hiatus, severe epigastric pain and a rigid abdomen may be found (as was present in Case 3), but the associated respiratory symptoms of dyspnea, grayish cyanosis, a short grunting type of respiration, and evidence of hypoxia should direct attention to the thorax as the probable site of the lesion Samson[9] has stressed the development of a nasal twang to the patient's voice which may precede the appearance of the supraclavicular subcutaneous emphysema, the latter being one of the dominant physical findings in most cases.

In ruptures of the cervical esophagus there is usually exquisite local tenderness, crepitus, and the patient holds the neck quite rigid in order to resist any local movement. Again this lesion is associated with dysphagia, salivation, and dysphonia.

An erect posteroanterior x-ray of the chest taken so as to include the diaphragm and upper abdomen should be obtained in all cases of suspected rupture of the esophagus. If the thoracic esophagus is ruptured the roentgenogram will usually show mediastinal emphysema with or without demonstrable fluid and pleural involvement in the form of hydrothorax or pneumothorax. These findings may or may not be present in cervical ruptures as they would depend upon the duration of the rupture and upon whether or not the mediastinal pleura has been penetrated. A lateral cervical x-ray will show air in the cervical tissues especially behind the esophagus, pushing the visceral compartment anteriorly. A Lipiodol swallow, never barium, under fluoroscopy which shows extravasation into the periesophageal tissues is confirmatory of the diagnosis and was present in each of the 11 of our cases in which the procedure was done. In Case 7 this was not deemed necessary since the perforation was visualized at the time of original endoscopy. Usually esophagoscopy is neither indicated nor desirable in these cases.

"Spontaneous-traumatic" rupture of the esophagus must be considered in the differential diagnosis of any upper abdominal emergency, of spontaneous pneumothorax, and of acute coronary disease. Before the lesion was widely recognized, some patients were operated upon for ruptured duodenal and gastric ulcer with the true lesion remaining unrecognized, causing embarrassment to the surgeon and yielding no particular benefit to the patient (Carter[4]).

THERAPY

As stressed by Samson,[9] the treatment of a ruptured esophagus should be that which applies to the rupture of any hollow viscus. The mere fact that the viscus lies in the neck or the thorax in no way materially affects the problem. Rapid resuscitation, of which surgery is an integral part (Beecher[3]), definitive surgical repair following débridement and lavage of contaminated fascial spaces, vigorous supportive therapy in the form of complete and rapid pulmonary expansion, constant tracheobronchial toilet effected by tracheotomy if necessary, whole blood, and massive combined antibiotic therapy constitute the fundamentals of the treatment of a ruptured esophagus. Following these principles Weisel[12] has *recently reported* 7 consecutive cases so treated with survival and without major complications in any of them.

A high mortality and higher morbidity rate accompany drainage procedures alone during the stage of contamination, which may be as long as twenty-four hours postrupture or more depending upon the underlying esophageal pathology and the treatment or lack of treatment which the patient receives prior to surgery. Five of 6 such cases collected by Samson[9] were fatal and the sixth case showed prolonged morbidity with pleural and mediastinal sepsis If a patient survives the stage of contamination, and an invasive infection is present with some degree of localization, drainage procedures are of value but even then the mortality is considerable and the morbidity high

Definitive repair in such late cases may not be attended with a high percentage of primary healing, however, except in the face of frank abscess formation we believe that primary repair should be attempted These patients appear to be and usually are desperate surgical risks, especially those with rupture of the thoracic esophagus, however, it must be repeated that surgery is the integral part of the resuscitation and the experience has been common that once the mediastinum has been widely opened and decompressed, the condition of the patient has materially improved so that more deliberate débridement and repair can be carried out

For ruptures of the cervical esophagus, we commonly have used local infiltration anesthesia and made an oblique incision along the anterior border of the sternomastoid muscle, similar to the approach we use for the removal of pharyngoesophageal diverticula The edema and emphysema in the fascial tissue planes usually make exposure of the esophagus medial to the vascular compartment quite easy After the perforation is visualized, a two-layered repair is carried out using fine cotton or silk sutures on Atraumatic needles for the mucosal layer with the interrupted sutures so placed that the knots are tied on the lumen side The outer muscle layer is sutured with similar material placed as horizontal mattress sutures The closure is transverse so as not to decrease the diameter of the esophageal lumen The fascial space having been primarily débrided and lavaged with saline, a Penrose drain is placed in the posterior mediastinal pocket and brought out from the lower angle of the wound and the subcutaneous tissues and skin are loosely approximated with cotton sutures The drain is placed well away from the line of esophageal repair A culture is taken from the contaminated tissues and the patient is placed on massive combined antibiotic therapy until the results of the cultures and sensitivity tests indicate the specific antibiotic to be used During the first 48 to 72 hours, the patient is placed in bed in a head down position in order to facilitate drainage from the upper mediastinum The patient is started on small amounts of clear oral liquids after twenty-four hours and the diet is then increased slowly

In perforations of the thoracic esophagus, we feel that in most instances thoracotomy, with wide incision and débridement of the mediastinal pleura, *primary repair of the site of rupture, and rapid expansion of the lung by* underwater-seal drainage, is the preferable treatment An occasional case may demand a different approach Overholt[13] reports a case that he saw eight days after perforation at which time the patient had a bilateral empyema which responded satisfactorily to bilateral tube drainage In Case 3 the perforation had occurred through the site of a stricture of the supradiaphragmatic esophagus and it was necessary that a resection of the area be done with primary esophagogastrostomy *It was interesting in this case,* that, due to an unavoidable delay of nearly six hours in getting this patient to the operating table, we saw him develop the typical, clinical picture that is seen in a case of ruptured peptic ulcer.

CASE REPORTS

CASE 1.—M. T., a 79 year old obese white woman, was admitted to Charity Hospital on Dec. 30, 1950. She had choked on a bolus of food at dinner on the same day and was having difficulty swallowing. A general physical examination showed no significant abnormalities and the patient was esophagoscoped under local anesthesia. A large bolus of meat was removed from the pyriform sinus and the endoscopist reported seeing a tumor mass in the esophagus at the 22 cm. level. A biopsy of the lesion was taken.

Within a very short period following endoscopy, the patient became quite restless and dyspneic. She received 6 grains of phenobarbital throughout the night but the restlessness and dyspnea increased. The Thoracic Surgery Resident saw the patient in consultation approximately twenty six hours after endoscopy. At the time of his examination the patient was irrational, exhibited acute respiratory distress, and was cyanotic. The blood pressure was 102/64 mm. of mercury and the pulse rate was 120 per minute and of poor quality. There was palpable subcutaneous emphysema in the supraclavicular areas and over the anterior thorax. Breath sounds were inaudible over the right hemithorax. An erect roentgenogram of the chest revealed a right tension hydropneumothorax. An endothoracic catheter was placed in the right pleural space and connected to an under water trap bottle allowing the escape of a large amount of air and several hundred cubic centimeters of a seropurulent fluid. The patient was given nasal oxygen, a whole blood transfusion, a massive dose of parenteral antibiotics, and was operated upon.

Approximately twenty nine hours after endoscopy, with the patient under gas oxygen ether anesthesia, a right posterior mediastinotomy was performed. The blood pressure was not obtainable at the time the incision was made. The posterior portion of the right third rib was resected very rapidly and the parietal pleura was mobilized giving access to the upper part of the posterior mediastinum. A considerable quantity of purulent fluid and air was evacuated. Two soft rubber catheters were introduced into the mediastinal pocket and connected to an underwater trap and the wound was sealed with petrolatum gauze. The entire operative procedure required ten minutes and, as soon as the mediastinum was decompressed, the blood pressure rose rapidly to 90/60 mm. of mercury.

Although the patient showed some improvement in her general condition during the first forty eight hours after operation, she continued to run an extremely severe febrile course with progressive symptoms of overwhelming toxicity. She developed signs of phlebothrombosis of the left lower extremity and under local anesthesia, a bilateral superficial femoral vein ligation was performed. In spite of massive antibiotic therapy and whole blood transfusions, the patient died on the eighth postoperative day. Unfortunately, an autopsy could not be obtained upon this patient.

Comment.—Due to the length of time from the perforation until we first saw the patient, her advanced age, and apparently moribund condition at the beginning of the operation only a rapid mediastinotomy was done. Although she improved temporarily, the mediastinitis was not controlled. In view of our later experiences and the reported experiences of others, we probably should have continued with a formal thoracotomy with definitive repair of the esophagus after the decompression of the mediastinum had been accomplished and the patient was definitely improved. This case illustrates the high morbidity and mortality rates following other than definitive control of the lesion.

CASE 2.—H. F., a 63 year old emaciated Negro man, was admitted to Charity Hospital on May 23, 1951. He stated that for the past two months he had noted progressive difficulty with swallowing, first for solid foods and than rapidly thereafter for semisolids and finally for liquids. He was severely dehydrated upon admission. Except for the severe malnutrition, the physical examination revealed no significant abnormalities. A roentgenogram of the chest was interpreted as within normal limits. An esophagogram showed an irregular, constant filling defect of the esophagus at the level of the aortic arch and extending inferiorly for approximately six cm. Esophagoscopy was performed under local anesthesia on May 29, 1951, and the endoscopist reported "a smooth angular constricting lesion at the junction of the middle and upper one third of the esophagus with complete fixation of the esophagus." The patient complained of pain in the neck and increasing salivation and dysphagia following the procedure.

We were consulted thirty hours after esophagoscopy and found the patient acutely ill, moderately febrile, disoriented, and with a fast, thready pulse. There was palpable subcutaneous emphysema of the anterior supraclavicular areas. An erect anterior and lateral roentgenogram of the chest showed emphysema of the soft tissues of the neck, a widening of the visceral compartment, and widening of the supracardiac shadow but no pneumothorax. A Lipiodol swallow under fluoroscopy revealed extravasation of Lipiodol into the retroesophageal space at the level of the fourth thoracic vertebra.

The patient was given a whole blood transfusion, nasal oxygen, massive antibiotics parenterally, and was operated upon thirty-four hours after the endoscopic perforation. A left cervical mediastinotomy, under local anesthesia, was done with the evacuation of about 200 c.c. of foul, seropurulent material. A Penrose drain was placed into the posterior mediastinal pocket and the subcutaneous tissue and skin closed loosely with multiple, interrupted, nonabsorbable sutures.

During the initial seventy-two postoperative hours the condition of the patient remained critical, after which he showed progressive improvement. On June 7, 1951, a tube gastrostomy for feeding was done. The patient refused further surgical therapy and on June 19, 1951, was started on a course of deep x-ray therapy. Following the completion of the x-ray therapy, he was able to swallow semisolid foods and was last seen in June of 1952 at which time he was in a preterminal condition with widespread pulmonary metastasis.

Comment.—Due to the frank abscess cavity that was present in the upper part of the posterior mediastinum, no attempt at primary closure of the esophageal defect was made in this case. The exact location of the perforation was not visualized.

CASE 3.—D. B., a 16-year-old undernourished white male, was admitted to Charity Hospital on Jan. 3, 1952. In 1948, in another city, following esophagoscopy for the removal of a foreign body, the patient had developed a right basal empyema that had required right thoracotomy and tube drainage for one month. Since that time, the patient had noted difficulty in swallowing solid foods. Recently the dysphagia had become more marked, and on admission the patient could swallow only very soft foods and liquids.

A roentgengoram of the chest showed an old operative defect in the right ninth and tenth ribs posteriorly. The physical examination gave evidence of chronic malnutrition and a well-healed operative scar in the right posterior chest wall. An esophagogram showed a smooth, linear stricture at the lower end of the esophagus (Fig. 1). Esophagoscopy revealed "a smooth, linear stricture beginning at 36 cm. from the incisor teeth and extending to the cardia."

On Jan. 9, 1952, the esophagus was dilated with a No. 40 F. Hirsch bougie. On Jan. 16, 1952, repeat bouginage with a No. 46 F. bougie was unsuccessful. Immediately following this attempt, the patient complained of severe presternal pain. This was at 10:00 A.M. and the Thoracic Surgery Service was consulted immediately.

On examination we found the patient to be in acute distress, ashen gray in color, and sweating profusely. The pulse was fast and weak, the respirations were rapid and shallow. The patient objected strenuously to being moved. He lay on his right side with the knees drawn up on the abdomen. There was no subcutaneous emphysema palpable and examination of the thorax did not reveal any significant abnormalities at that time. During the course of one hour following the attempted dilatation, the abdomen became very tender and showed a boardlike rigidity. The patient presented the clinical picture of a ruptured duodenal ulcer. An erect roentgenogram of the chest, including the upper abdomen, showed essentially negative intrathoracic findings but a small amount of free air was visible under both leaves of the diaphragm. A Lipiodol swallow revealed extrav asation of the oil outside the esophagus 3 to 4 cm. above the diaphragm on the posterior wall with the Lipiodol extending below the diaphragm into the lesser peritoneal sac (Fig 2)

A diagnosis of traumatic perforation of the distal esophagus at the site of stricture was made The patient was given a massive dose of antibiotics parenterally (penicillin, streptomycin and Terramycin) nasal oxygen, a whole blood transfusion and Demerol for sedation. He was operated upon by one of us (J W O) six hours postperforation and a posterolateral thoracotomy was performed through the left seventh interspace

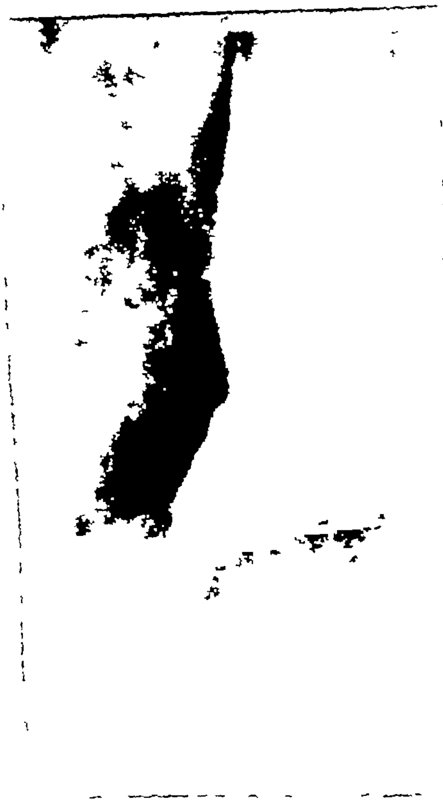

Fig 1

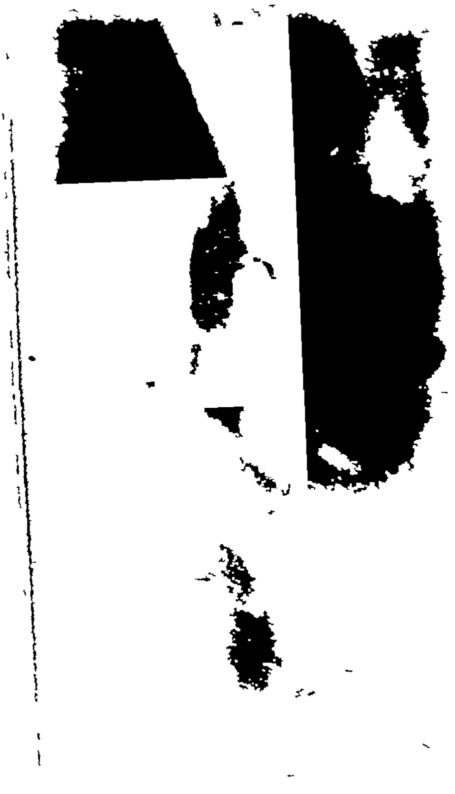

Fig 2

Fig 1 —Case 3 Esophagogram made prior to dilatation showing high degree of stricture in the lower esophageal segment.

Fig 2 —Case 3 Lipiodol esophagogram made immediately after perforation which occurred during bouginage Lipiodol is seen in periesophageal tissues

Upon opening the chest the left lung was found to be free and there were approximately 100 c c of a cloudy serous fluid in the pleural space The mediastinal pleura was intact but quite edematous The lower mediastinal pleura was incised and the esophagus freed with some difficulty due to extensive scarring present which apparently was secondary to the previous periesophageal infection which had followed the removal of the foreign body A one inch laceration was found on the posterior wall of the esophagus immediately above the diaphragm in an area of intense scarring and stricture formation It was apparent that the perforation could not be closed without compromising the already greatly narrowed esophagus so a resection of the lower 10 cm. of the esophagus was done and an esophagogastrostomy performed The left chest was drained with two large endothoracic catheters connected to a water seal bottle and the chest incision closed in anatomical layers with interrupted nonabsorbable sutures

The postoperative course of the patient was uneventful A Levin tube, which had been inserted into the stomach following the anastomosis, was removed in forty eight hours and the patient placed on oral liquids On the sixth postoperative day he was taking a soft surgical diet He was discharged from the hospital on the eleventh postsurgical day The patient gained eight pounds during the first postoperative month He has remained well, eating a full diet without difficulty An x ray with a barium meal taken one month after the operation showed a normally functioning stoma without evidence of stricture or esophagitis (Fig 3)

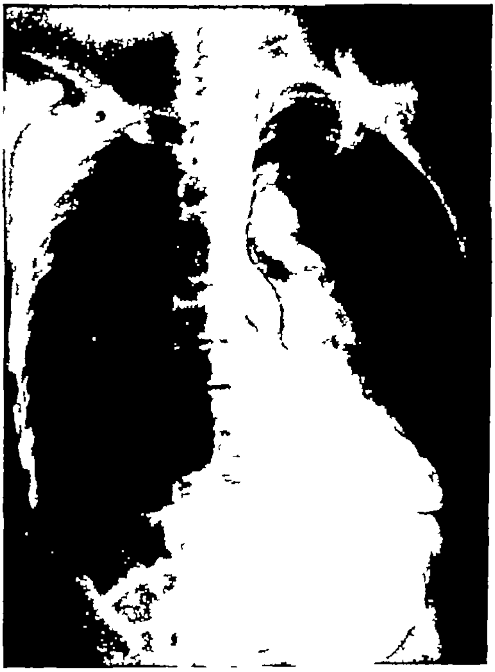

Fig 3 —Case 3 Esophagogram one month after esophagogastrostomy showing normally functioning stoma.

Comment —This patient presents the interesting findings of having survived two apparent esophageal perforations four years apart, the second rupture necessitating immediate esophageal resection with restoration of continuity by esophagogastrostomy This patient was subsequently seen one year following surgery at which time he was continuing to do well without evidence or symptoms of esophagitis

CASE 4 —A S, a 71 year old Negro man, at 7 A M on Sept 14, 1952, swallowed a chicken bone that lodged in his throat "just below my Adam's apple " He ate a large amount of bread and rice in trying to dislodge the bone, but was unsuccessful At 11 30 A.M his local physician passed a bougie in an attempt to dislodge the bone After the third attempt, the patient developed a severe pain in the midline of the upper thorax posteriorly and noted within a period of five minutes that the neck was becoming swollen The patient was referred to the Charity Hospital in Lafayette, Louisiana No thoracic surgeon was available at that institution so the patient was given one million units of penicillin, 500 mg of Aureomycin intravenously, and referred on to the Charity Hospital in New Orleans The patient was first seen in the Emergency Room of the Charity hospital in New Orleans by the Thoracic Surgery Resident at 4 00 A.M on Sept 14, 1952 He was semicomatose and exhibited marked dyspnea, dysphagia, limited ability to talk, and marked subcutaneous emphysema of the supraclavicular areas An erect roentgenogram of the chest revealed extensive mediastinal emphysema with a questionable fluid level visible A Lipiodol swallow under fluoroscopy showed extravasation into the upper mediastinum The patient was given a whole blood transfusion, nasal oxygen, massive combined antibiotics parenterally, and was operated upon at 6 00 A M on Sept 15, 1952, approximately eighteen hours after perforation

The patient was operated upon by one of us (J W O) through a right posterolateral incision, resecting the fifth rib A complete synechia of the pleural space was found After freeing the lung, the mediastinal pleura was seen to be fiery red, very edematous, and tense The azygos vein was ligated and the mediastinal pleura widely opened from the thoracic inlet to below the right inferior pulmonary vein A considerable amount of foul fluid and air was evacuated along with beans, rice, bread, and undigested lumps of chicken Three cm below the inferior pulmonary vein, a chicken bone measuring approximately 4 cm long by 3 mm in diameter was removed from the retroesophageal area No point of perforation could be visualized but in the lower cervical esophagus a perforation on the posterior wall could be palpated. The mediastinal pleura was widely débrided and the entire area lavaged with a large amount of saline The chest was closed in anatomical layers using interrupted sutures of cotton The pleural space was drained by two No 34 F rubber catheters connected to an underwater drainage bottle The general condition of the patient improved very markedly as soon as the mediastinum was decompressed After the thoracotomy incision was closed, the patient was turned to a supine position and the cervical esophagus explored through an oblique incision in the right side of the neck The perforation was located on the posterior wall at the level of the second tracheal ring Closure of the defect was carried out using two layers of interrupted sutures of No 4-0 silk. The wound was closed without primary drainage from the neck although the cervical retroesophageal area communicated freely with the thoracic mediastinal space that was drained by the two intrapleural tubes

Postoperatively, the patient did extremely well He was afebrile in 48 hours and was started on oral fluids at that time At *no* time was there evidence of further esophageal leakage On the fifth postoperative day he developed a small sterile serous effusion on the left side that was aspirated and did not recur He was given a soft diet on the sixth postoperative day and was discharged on the sixteenth postsurgery day He was followed in the outpatient clinic at *intervals for* over one year and had no further difficulties

Comment—This case clearly illustrates the major clinical features of traumatic esophageal perforation and the excellent results which commonly follow vigorous resuscitation and definitive surgical therapy

CASE 5—L. H , a 54 year old Negro woman, was admitted to Charity Hospital at 4 00 A.M on Nov 12, 1952 complaining of a ' bone'' stuck in her throat The admission physical examination was reported as showing no significant abnormalities Esophagoscopy was performed at 9 00 A M on the same day under local anesthesia and the report stated 'no foreign body seen '' The patient stated that immediately after endoscopy she noted the onset of severe pain in the neck, became progressively short of breath, and developed a swollen neck She had marked difficulty in swallowing her saliva In spite of these symptoms, she was discharged from the hospital by the admitting service at 6 00 P M the same day

The patient stated that she became progressively more ill at home and at 4 00 A M she returned to the Emergency Room at Charity Hospital She was first seen by the Thoracic Surgery Resident six hours later The patient at that time was very dyspneic, moderately febrile, with pain and tenderness in the cervical areas, and extensive subcutaneous emphysema of the face and neck An erect roentgenogram of the chest showed no pneumothorax. A Lipiodol swallow under fluoroscopy showed extravasation of the contrast medium outside the esophagus in the upper cervical region. The patient was given a whole blood transfusion, massive combined antibiotics parenterally, nasal oxygen, and transferred to the surgical service.

The patient was operated upon at 2:00 A.M. on Nov. 14, 1952, thirty-nine hours after endoscopy. As anesthesia was induced, the patient developed laryngeal obstruction and an emergency tracheotomy was done. Through a left anterior cervical incision, the esophagus was mobilized and a perforation on the posterior wall immediately below the cricopharyngeus muscle was repaired with two layers of interrupted nonabsorbable sutures. The patient was given liquids by mouth in forty-eight hours and on the fourth postoperative day the signs of a small esophageal fistula were noted. A feeding gastrostomy was done. Her further course was uncomplicated. By Dec. 16, 1952, no evidence of the fistula remained and the gastrostomy tube was removed. She has remained well since that time.

Comment.—In spite of the prolonged duration between perforation and repair, the patient rapidly improved after surgery. The esophageal fistula that developed was apparently quite small and probably could have been controlled by the passage of a soft, plastic feeding tube without resort to gastrostomy.

Fig. 4.—Case 6. Lateral cervical roentgenogram after Lipiodol swallow showing retro-esophageal extravasation of contrast media and anterior displacement of the visceral compartment.

Case 6.—L. M., a 27-year-old Negro woman, was admitted to the H. P. Long Charity Hospital in Pineville, Louisiana, on Feb. 4, 1953, shortly after having been shot three times with a small-caliber pistol. There was a wound of entry above the point of the left shoulder, another to the right of the midline of the middle of the neck anteriorly, and three perforations on the lateral aspect of the right forearm. An erect roentgenogram of the chest revealed a fracture of the left first rib posteriorly but there was no pneumothorax. An esophagogram using Lipiodol revealed extra-esophageal oil in the region of the seventh cervical vertebra with widening of the prevertebral visceral space (Fig. 4).

The general condition of the patient was satisfactory. She was operated upon while receiving a whole blood transfusion and massive combined antibiotics parenterally. This was approximately six hours after the time of injury. The left side of the neck was explored through an incision along the anterior border of the sternomastoid muscle. The point of perforation of the esophagus was found immediately below the cricopharyngeus. The wound was débrided and the defect in the esophagus was closed with separate layers of mucosal and muscular sutures of quilting cotton. The operative wound was closed without drainage using interrupted cotton sutures.

Her postoperative recovery was entirely uneventful. Being able to take a normal diet she was discharged from the hospital on the fifteenth postsurgery day.

CASE 7.—L. W., a 49-year-old white woman, was admitted to Charity Hospital on Feb. 28, 1953, with a history of massive gastrointestinal bleeding. Extensive clinical investigation revealed no abnormalities other than a large sliding hiatal hernia. Further questioning revealed symptoms compatible with peptic esophagitis. Under local anesthesia, esophagoscopy was performed on March 11, 1953, at 10:00 A.M. Shortly after the procedure the patient stated she noted the onset of severe pain in the neck and some swelling, both of which became progressively worse and were associated with excessive salivation and difficulty in swallowing. She was seen by the Thoracic Surgery Service the next morning and a clinical diagnosis of esophageal perforation was made. A Lipiodol swallow under fluoroscopy revealed extravasation of the oil outside the esophagus into the neck.

Twenty-eight hours after endoscopy the patient was operated upon through a left anterior cervical incision and a perforation on the posterior wall of the esophagus was closed in layers with nonabsorbable sutures. Two drains were left in the superior mediastinal space. The patient received intravenous fluids and large doses of combined antibiotics parenterally. Oral fluids were started on the third postoperative day. A small fistula was apparent on the fifth day after surgery. A temporary feeding gastrostomy was done on March 22, 1953, and oral feedings were discontinued until April 1, 1953, when methylene blue taken by mouth showed that the fistula had closed. The gastrostomy tube was removed and the patient's further course was uneventful. She was discharged from the hospital on April 17, 1953.

She was readmitted to Charity Hospital on June 8, 1953, at which time an esophagogram showed no residual defect. One of us (A. O.) repaired the large sliding hernia, using the Allison technique.

Comment.—The immediate response of the patient after surgery was excellent and due to the small size of the fistula that developed, it was probably not absolutely necessary that the feeding gastrostomy be done.

CASE 8.—E. C., a young Negro man, was admitted to Charity Hospital on April 12, 1953, one hour after having been stabbed in the right anterior neck. The blood pressure on admission was 86/50 mm. of mercury. There was brisk arterial bleeding from a 3 cm. laceration in the right side of the neck just above the right clavicle at the anterior border of the sternomastoid muscle. There was subcutaneous emphysema in the left supraclavicular area. The hematocrit was 34 volumes per cent. A roentgenogram of the chest was not abnormal. The patient was operated upon two hours and forty-five minutes after his injury while receiving whole blood transfusions and massive combined antibiotics parenterally.

Through a right oblique anterior cervical incision, a large transverse laceration of the posterior wall of the cervical esophagus was found and repaired with an inner layer of No. 00 chromic catgut and an outer muscular layer of quilting cotton. The major point of bleeding was from the right superior thyroid artery which was ligated. A small rubber dam drain was brought out through the lower angle of the incision and the subcutaneous tissues and skin closed with multiple interrupted sutures of quilting cotton.

The postoperative course was completely uneventful and a barium swallow on May 4, 1953, showed no residual defect in the esophagus.

CASE 9—E T, a 78 year old white man, was admitted to Charity Hospital complaining of weakness, upper abdominal pain, and recent hematemesis and tarry stools The general physical examination was not remarkable and roentgenographic studies of the gastrointestinal tract were normal except for a small hiatal hernia and sigmoid diverticulosis

In order to rule out esophagitis or varices, on April 29, 1953, at 8 00 A M, the patient was esophagoscoped under local anesthesia There was difficulty in introducing the esophagoscope and at 9 00 A M., we were called to the endoscopy room to see the patient The esophagoscope was still in the esophagus and there was an obvious perforation on the posterior wall just below the cricopharyngeus The patient was given 1,000,000 units of penicillin, 1 Gm of streptomycin, luminal, and atropine and was transferred to surgery

Two hours after the perforation, under local anesthesia, the esophagus was explored through an oblique incision along the anterior border of the left sternomastoid The perforation was visualized on the posterior wall and a two layer closure with fine interrupted silk sutures was performed The integrity of the anastomosis was tested by having the patient swallow methylene blue solution which revealed a water tight closure A small rubber drain was left in the upper mediastinum and the operative wound closed The patient was given oral liquids on the first postsurgery day With the exception of a severe penicillin rash that developed on the eighth postoperative day his clinical course was completely uneventful

Comment—*This is the only case in this series in which the endoscopist recognized the* site of perforation when it occurred

CASE 10—L J, an 88 year old undernourished Negro woman, was admitted to Charity Hospital on April 27, 1953, where she was studied extensively for a marked anemia of undetermined etiology Gastroscopy was performed on May 6, 1953, at 9 00 A.M and the endoscopist stated that there was "some difficulty in passing the gastroscope" Shortly after the procedure, the patient complained of severe pain in the neck and developed a rising pulse rate, fever, and moderate dyspnea A roentgenogram of the chest showed subcutaneous emphysema in the base of the neck, bilaterally with a moderate right pneumothorax.

We saw the patient in consultation eight hours after endoscopy A Lipiodol swallow, under fluoroscopy, showed extravasation of the dye from the upper esophagus The patient was critically ill at that time An endothoracic tube was placed in the right pleural space and connected to an underwater drainage bottle Approximately 300 c c of seropurulent fluid and a large amount of air was removed The patient was given a whole blood transfusion, massive combined antibiotics parenterally, nasal oxygen, and was transferred to surgery

Under local anesthesia, the cervical esophagus was explored through an oblique incision and a perforation was found on the posterior wall which was repaired with two layers of interrupted sutures of fine silk. A fine rubber dam drain was placed into the superior mediastinum and because of the patient's critical condition and the pulmonary complications, a tracheotomy was performed also The operation was carried out approximately thirteen hours after the endoscopy

Postoperatively the condition of the patient steadily improved, the only complication being a *persistent middle lobe atelectasis which required bronchoscopy through the* tracheotomy stoma The patient was given liquids by mouth on the second postoperative day and a soft diet on the seventh day after operation The endothoracic tube was removed on the third postoperative day as the lung was completely expanded and there was no evidence of pleural infection A Lipiodol swallow on the thirteenth day showed no esophageal defect

Comment—We feel confident this very elderly, critically ill patient would not have survived without vigorous definitive therapy This case further illustrates the value of *tracheotomy* in the management of critically ill patients with pulmonary complications

CASE 11—L. F, a 64 year old white woman, was admitted to Charity Hospital with a one year history of indigestion and epigastric pain that was relieved by alkalis

On April 19, 1953, the patient vomited about "one pint of bright red blood and fainted. She was admitted to the Emergency Room in mild shock and shortly thereafter went into deep shock after passing two large tarry stools and vomiting a small amount of bright red blood. She responded to multiple whole blood transfusions and the bleeding apparently subsided promptly. The patient was studied extensively by proctoscopy and roentgenographic studies of the entire intestinal tract as well as hematologic and liver studies, failed to reveal the etiology or source of the bleeding.

On May 18, 1953, abdominal exploration under endotracheal anesthesia was performed. During the course of the operation a Levin tube was passed with the aid of a laryngoscope by the anesthetist. No demonstrable pathology or cause of the bleeding was found at operation. At the conclusion of the operation, her condition was reported as satisfactory.

At 9:00 A.M. of the first postoperative day it was noted that the left side of the patient's neck was swollen and tender to palpation and that subcutaneous emphysema was present. A roentgenogram of the neck showed air in the retroesophageal space and a Lipiodol swallow showed extravasation of the contrast medium into the periesophageal tissues in the region of the seventh cervical vertebra.

The patient was operated upon approximately thirty hours after the previous abdominal exploration. The cervical esophagus was explored under local anesthesia. A perforation of the hypopharynx on the left lateral wall was found just above the cricopharyngeus. The tissues were very edematous and indurated. Closure of the perforation was performed by two layers of interrupted nonabsorbable sutures. The patient was acutely ill and disoriented at the time of exploration. A small rubber wick drain was inserted into the upper mediastinum and brought out through the lower end of the wound.

The postoperative course of this patient was quite complicated. Two days after operation there was clinical evidence of moderately severe electrolyte imbalance which responded to increased amounts of sodium chloride and potassium chloride solutions. On May 22, 1953, a cervical fistula was apparent. In spite of the fistula she was continued on oral fluids and was showing steady improvement until she was given aureomycin orally on May 29, 1953. She promptly developed a severe diarrhea followed shortly by increasing evidence of partial small bowel obstruction. On June 1, 1953, the abdomen was re-explored and an incomplete small bowel obstruction due to adhesions found. It was also reported that the entire small bowel and colon were extremely hyperemic and edematous. It was felt this picture was compatible with a diffuse enteritis, probably related to the use of the broad spectrum antibiotic.

Her convalescence was slow thereafter but the cervical fistula progressively decreased in size and closed without further operative procedures.

Comment.—It is felt that in this case the perforation of the hypopharynx occurred either at the time of insertion of the endotracheal tube or during the operative procedure when the Levin tube was passed with the aid of the laryngoscope. The fact that she was recovering from the effects of a general anesthetic and had received narcotics during the afternoon and evening of the day of operation probably prevented the earlier appearance of symptoms referable to the ruptured hypopharynx. Morbidity in this case was extensive but was in large part due to the abdominal complications.

CASE 12.—L. G., a young Negro man, was admitted to the H. P. Long Charity Hospital in Pineville, Louisiana, on May 24, 1953, two hours and fifteen minutes after having been stabbed in the right side of the neck. The wound of entrance was along the anterior border of the sternomastoid muscle and the blade of the knife could be palpated in the depth of the wound. The neck was very tender and there was extensive subcutaneous emphysema but the general condition of the patient was satisfactory. A roentgenogram of the neck revealed a knife blade extending transversely in the lower neck at the level of the fifth cervical vertebra (Figs. 5 *A* and *B*). A roentgenogram of the chest taken in the erect position at the time of admission showed no pneumothorax and a Lipiodol swallow showed extravasation of the oil into the retroesophageal tissues of the neck.

The patient was given a whole blood transfusion and a massive dose of combined parenteral antibiotics and was operated upon three and one-half hours after injury. The

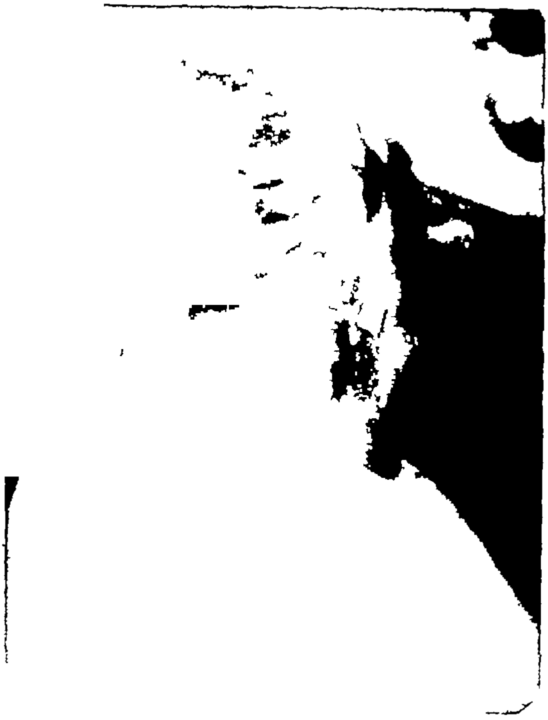

Fig 5A.—Case 12 Lateral roentgenogram of the neck showing presence of foreign body subcutaneous emphysema and air in the retrovisceral space.

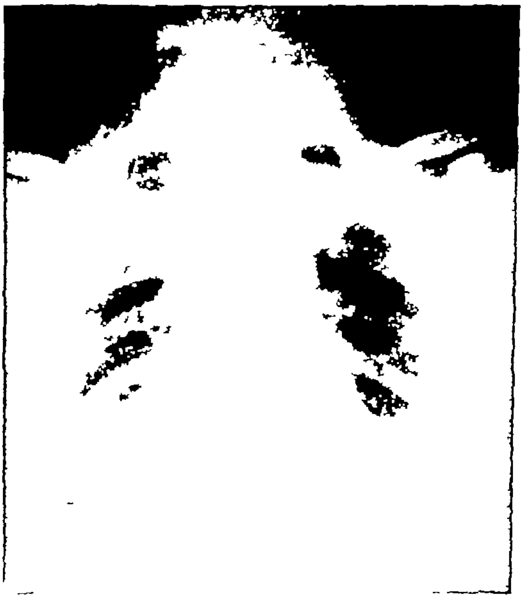

Fig 5B.—Case 12 Roentgenogram of chest including the cervical area showing a knife blade lying transversely in the neck and extravasation of Lipiodol outside the esophagus

neck was explored through bilateral oblique incisions and the knife blade was found to lie immediately anterior to the carotid artery on the right side. The blade had penetrated the esophagus posteriorly giving an entrance and exit wound with a small area of intact esophagus between the openings. The esophageal perforations were closed with interrupted sutures of quilting cotton on the mucosa and the muscle layers. The operative wound was closed without drainage.

The postoperative course was without complications. The patient was given oral liquids on the first postoperative day and the diet was steadily increased. He was continued on large parenteral antibiotic dosage for seven days. The patient was discharged from the hospital on the fourteenth postoperative day as he was eating normally and was asymptomatic.

CASE 13.—D. B., a 23-year-old Negro man, was admitted to H. P. Long Charity Hospital in Pineville, Louisiana, on June 7, 1953, approximately five hours after having been shot in the left midneck immediately lateral to the trachea. The bullet could be palpated in the subcutaneous area of the right shoulder girdle. There was swelling and subcutaneous emphysema in the right supraclavicular fossa. The blood pressure was 130/90 mm. of mercury and the pulse rate was 100 per minute. The general condition of the patient was satisfactory. A lateral roentgenogram of the neck showed subcutaneous emphysema and air in the retroesophageal space. A Lipiodol swallow under fluoroscopy in the anterior and lateral projections revealed extravasation of the oil into the right periesophageal tissues.

Under general anesthesia the neck was explored and a laceration of the esophagus on the posterior wall was found. The operative wound was closed without drainage. The patient was given large doses of parenteral antibiotics. He was given oral liquids on the second postoperative day and was taking a regular diet on the seventh day at the time of his discharge from the hospital.

Comment.—The response of this patient was without any complications.

SUMMARY

1. Of thirteen cases of traumatic perforation of the esophagus treated by us from July 1950 to June 1953, eight were due to diagnostic or therapeutic endoscopy or bouginage, one occurred in the pyriform fossa during attempted passage of a Levin tube with the patient under endotracheal anesthesia, and four were due to penetrating injuries of the neck.

2. All patients were subjected to operation as soon as possible after the diagnosis was made and resuscitative and supportive therapy had been started.

3. Ten of the cases had primary repair with excellent results other than small temporary fistulas which developed in 3 of the cases. The duration of perforation prior to repair in those developing fistulas was forty-four hours, twenty-four hours and twenty-eight hours respectively.

4. Mediastinotomy and drainage were done in 2 cases. Case 1 had posterior mediastinotomy and intrathoracic underwater-seal drainage for massive infected pleural effusion and tension pneumothorax twenty-eight hours after perforation. She died on the eighth postoperative day. Case 2 had cervical drainage of a high mediastinal abscess thirty-two hours following perforation during biopsy of a high thoracic esophageal carcinoma.

5. The ages of the patients ranged from 16 to 88 years.

6. The time interval from perforation to surgery varied as extensively as did the ages, the intervals ranging from one and one-half hours to forty-four hours.

7 Of the 8 endoscopic perforations, 5 occurred immediately below the cricopharyngeus sphincter on the posterior esophageal wall, one occurred through a stricture immediately above the esophageal hiatus, and in the 2 in which drainage only was done the site was in the cervical or upper thoracic esophagus, but the opening was not visualized All four of the penetrating esophageal injuries occurred in the cervical segment

CONCLUSIONS

In closing, we can say that our experience has paralleled that of others Samson,[9] Weisel,[12] Mackler,[7] etc, in finding that prompt diagnosis, rapid resuscitation, surgical exploration with débridement of contaminated fascial planes, definitive repair of the esophageal defect, and vigorous postoperative supportive therapy are followed, in a large percentage of cases, by rapid and relatively uncomplicated recovery from this previously highly fatal accident

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HEMANGIOMA OF THE MEDIASTINUM

Review of Literature and Report of Case

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VASCULAR tumors are common tumors and are found most frequently in the skin and mucous membranes. They are found also in the central nervous system and abdominal viscera. The hemangioma is one of the commoner vascular tumors, but it is rare for a hemangioma to develop in the mediastinum. In fact, with one exception,[1] most recent reports of large groups of mediastinal tumors fail to mention its occurrence at all. This case was not discussed in sufficient detail to be included in this review. We were therefore surprised to encounter five vascular tumors in a recent review at the Mayo Clinic of mediastinal tumors in infants and children.[2] Two of these were hemangiomas, one of which had been reported previously.[3]

A review of the literature (Table I) reveals that all documented cases of this condition have appeared within the last 11 years. Because of the rarity of this condition and the likelihood that it will be encountered more frequently with the increasing use of exploratory thoracotomy for indeterminate mediastinal tumors, the following case is reported. In addition the literature has been reviewed in an attempt to determine whether any characteristics of this condition may lead to a correct preoperative diagnosis.

REPORT OF CASE

The patient, a 9-year-old boy, was first seen at the Clinic on Nov. 28, 1952.

There was no family history of significant diseases and the patient had been in good health during his early childhood. Because of vague symptoms of easy fatigability a mobile chest unit thoracic roentgenogram had been taken 3 months before admission. This was reported to be abnormal. There was no history of cough, hemoptysis, dyspnea, thoracic pain, or fever.

Physical examination revealed a blood pressure of 128 mm. of mercury systolic and 80 diastolic, a pulse rate of 76 per minute and a temperature of 98.9° F. There was a soft apical systolic murmur.

The results of laboratory studies including routine urinalysis, hemoglobin, erythrocyte and leukocyte counts and erythrocyte sedimentation rate were within normal limits. The cutaneous reaction to tuberculin was negative.

Roentgenograms of the thorax (Fig. 1) revealed a rounded shadow in the anterior mediastinum projecting into the left side of the thorax. Fluoroscopy of this mass demonstrated pulsations which seemed to be expansile in character.

Because of the presence of an indeterminate mediastinal mass, exploratory thoracotomy was advised. On Dec. 11, 1952, a left posterolateral incision was made and the left side of

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TABLE I PRIMARY HEMANGIOMA OF THE MEDIASTINUM

CASE	AUTHOR	YEAR	SEX AND AGE*	LOCATION IN MEDIASTINUM	SIZE OR WEIGHT	OPERATION	FOLLOW UP
Proved Cases, Photomicrographs Available							
1	Adams and Bloch[4]	1944	M34	Right midanterior	18 by 10 by 5 cm	Incompletely removed	Alive 4 years later
2	Bergstrom[5]	1945	F12 wk	Right anterior	—	No	Died
3	Bergstrom[5]	1945	F5 wk	Midanterior	8 by 5.5 cm	No	Died
4	Seybold et al[3]	1949	M59	Right midposterior	3.5 by 3.7 by 2.5 cm 12 Gm	Completely removed	Alive and well 8 years later
5	Thomas and Chesser[6]	1950	F18	Left midanterior	10 by 7.5 by 6.5 cm 275 Gm	Completely removed	Survived operation
6	Schlumberger[7]	1951	M26	Anterior	—	No	Died
7	Schlumberger[7]	1951	M19	Anterior	9 by 5 by 5 cm	Completely removed	Malignant mediastinal teratoma found subsequently
8	Maggi et al[8]	1952	M24	Right midanterior	—	No	Died
9	Sebestony[9]	1953	F47	Left midanterior	380 Gm	Completely removed	Survived operation
10	Grimes et al[10]	1953	F31	Right superior	6 by 8 cm	Completely removed	Survived operation
11	Maurer[11]	1953	M38	Left upper anterior	12 by 7 cm	Completely removed	Alive and well 5 weeks later
12	Valle[12]	1954	M23	Left lower anterior	8 by 10 cm	Completely removed	Alive and well 18 months later
13	Authors	1955	M9	Left upper anterior	6 by 5 by 4 cm.	Completely removed	Alive and well 2 years later
Unproved Cases, Photomicrographs Not Available							
14	Horst and Beatty[13]	1951	M20	Left anterior	18 cm diameter	Completely removed	Alive and well 33 months later
15	Tal'man[14]	1953	F42	Right midposterior	10 by 6 by 6.5 cm	Completely removed	Alive and well 4½ months later
16	Keegan[15]	1953	F18	Right midanterior	7 by 8 cm	Exploration, biopsy, x ray therapy	Alive and well 7 months later
17	Emery and Doxiadis[16]	1953	M8	Left upper anterior	14 by 16 by 8.5 cm	No	Died
18	Gross[17]	1953	—3mo	Left superior	—	Exploration, biopsy, x ray therapy	Alive and well 1 year later
19	Schorr et al[18]	1954	F56	Left midanterior	5 by 7 cm	Exploration, biopsy, x ray therapy	Alive and well 1 year later

*Years unless otherwise specified

the chest was entered through the bed of the resected fifth rib. High in the anterior mediastinum, a firm tumor mass overlay the aortic arch and extended up to the left innominate vein. The mass was dissected away from the surrounding structures without difficulty. A number of blood vessels which were ligated and divided seemed to enter its superior portion from the mediastinum. The chest was closed in layers after insertion of an intercostal tube through the ninth intercostal space for postoperative drainage.

The patient's postoperative course was uneventful. The chest catheter was removed on the third postoperative day and he was dismissed from the hospital after 8 days. Two years later the child is asymptomatic and the thoracic roentgenograms reveal no significant abnormality.

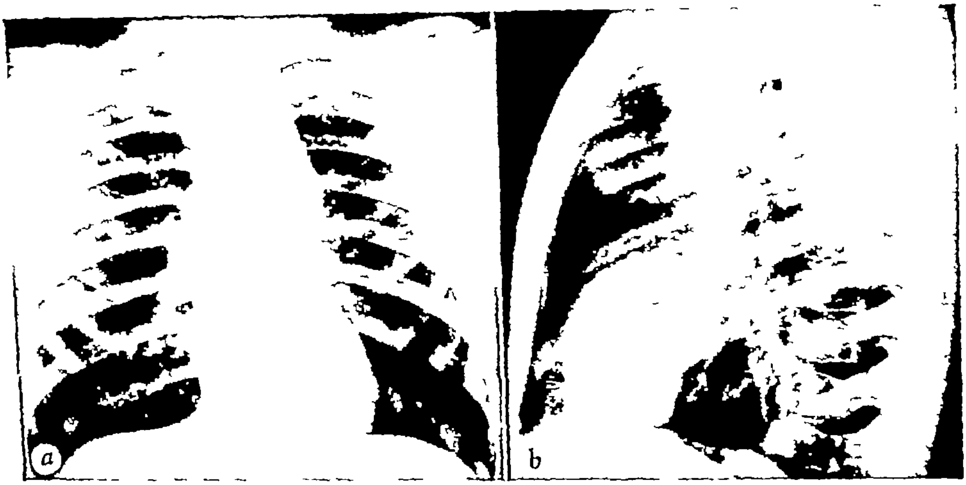

Fig. 1.—Thoracic roentgenograms in a case of mediastinal hemangioma. *a*, Posteroanterior projection: rounded tumor mass overlying the aortic shadow and projecting into the left side of the thorax. *b*, Left lateral view: tumor in the anterior mediastinum.

The specimen measured 6 by 5 by 4 cm. On cut section (Fig 2, *a*) it was seen to be made up of spongy vascular tissue with cystic spaces. Microscopic examination (Fig 2, *b*) revealed typical benign cavernous hemangioma. Proliferating smooth muscle cells were present in the septa.

COMMENT

A hemangioma is a benign neoplasm composed of numerous blood vessels of varying size and admixtures of other mesodermal tissues such as fibrous tissue, smooth muscle, and fat. It may be encapsulated or locally infiltrative, but it does not metastasize.

In reviewing the literature, an attempt was made to include only cases fitting this description in which the hemangioma was limited to the mediastinum. All cases of malignant vascular tumors were excluded. In so doing, some cases previously reported as hemangiomas of the mediastinum have been eliminated while others listed as hemangio-endotheliomas have been included. Hemangiomas of the diaphragm[19] and pericardium[20] were not included in this group of mediastinal hemangiomas. The two cases of Bergstrom[2] (Cases 2 and 3) in which the patients were newborn infants are however open to question as possibly being of pericardial or diaphragmatic origin. One case (Case 7) of Schlumberger in which later a malignant teratoma of the mediastinum was found is also open to question.

A total of 19 cases of hemangioma of the mediastinum have been reported, including the case reported here. Thirteen of these are classified as proved cases because photomicrographs compatible with this diagnosis were published in the reports. Six are unproved in the absence of photomicrographs, although in all likelihood they are all authentic cases. It is difficult to explain why no cases were reported prior to 1944.

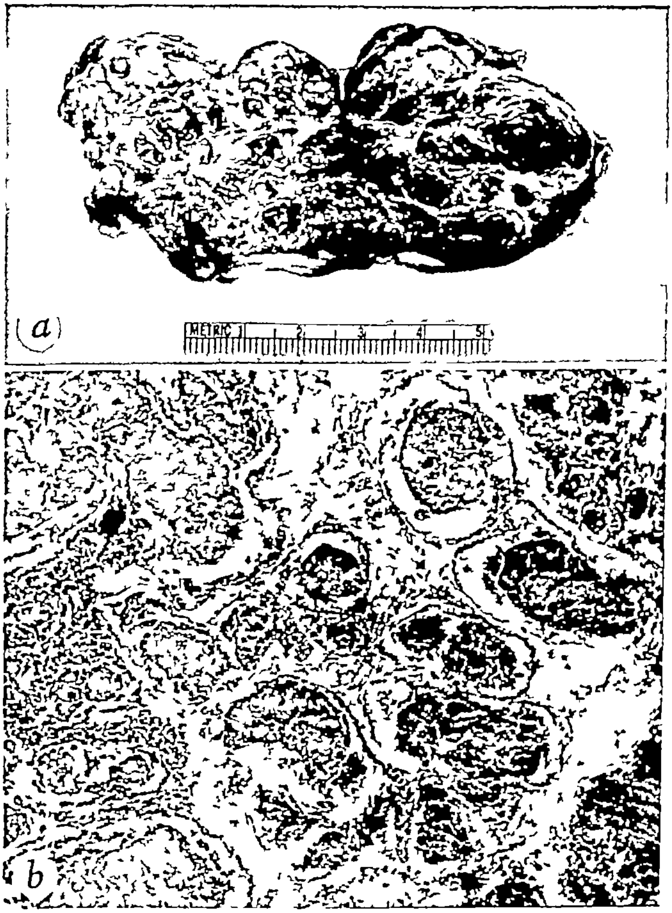

Fig. 2.—a, Cut surface of gross specimen of mediastinal hemangioma. b, Photomicrograph of a, multiple blood-filled spaces with varying amounts of intervening connective tissue and proliferative smooth muscle. (Hematoxylin and eosin ×75.)

Special Characteristics.—All age groups are represented in this series of 19 cases, beginning with the newborn period up to and including the sixth decade of life. The two sexes were equally affected. No characteristic symptoms were noted, many patients being completely symptom-free until a routine thoracic roentgenogram disclosed the tumor. Symptoms, when present, were the usual ones related to thoracic disease, for example, cough, thoracic pain, fever, and dyspnea.

Roentgenologically these tumors have a discrete curved outline and may be found either on the right or on the left side The most characteristic feature of this unusual condition is its location In only two cases was the tumor located in the posterior mediastinum In the remaining 17 cases the tumor was anteriorly located, either in the upper, mid-, or lower portion of the anterior mediastinum or in the superior mediastinum This consistently anterior mediastinal location is shared by only two other types of primary mediastinal tumors thymomas and teratomas

Origin and Pathology—No definite statements regarding the origin of mediastinal hemangiomas are justified from the available data although some speculations can be made Hemangiomas in general are considered as developing from vascular mesenchyme This angioblastic tissue remains discrete and separate from the other normally distributed cells which proceed to form the normal blood vascular pattern This concept assumes a congenital origin for hemangiomas, an assumption which is in keeping with the fact that vascular tumors of the mediastinum are more frequently encountered in children than in adults[2] Only one-fourth of the reported cases of hemangiomas of the mediastinum occurred in children however It is quite conceivable that many of the cases in adults would have been uncovered at an earlier age had thoracic roentgenograms been made sooner

It is tempting to relate hemangiomas to teratomas of the mediastinum Both neoplasms occur primarily in the anterior mediastinum The second case of Schlumberger (Case 7) lends some support to this concept A hemangioma was removed from the anterior mediastinum of an asymptomatic 19-year-old man one year before a malignant teratoma was removed from the same location Another vascular tumor associated with a mediastinal teratoma has been reported by Ehrenreich and associates[21] However, careful histologic sampling of the two mediastinal hemangiomas in the files of the Clinic, the one reported here and that of Seybold and associates,[3] fails to support a teratomatous origin of these tumors

The histologic appearance in the reported cases of mediastinal hemangiomas varies from that of a simple hemangioma composed of encapsulated blood vessels to a more complex picture Varying amounts of smooth muscle, fibrous tissue, fat and even bone are present in some cases Stout[22] has classified such tumors as mesenchymomas and has stated that they are probably initiated as a result of developmental faults and can be regarded as dysontogenetic growths

Treatment—Surgical removal is, of course, indicated in all cases of mediastinal hemangioma since it is unlikely that a correct preoperative diagnosis can be made In 14 of the 19 cases exploratory thoracotomy was performed In 10 of these 14 cases the tumor was completely removed without difficulty

In four cases the tumor was locally invasive and was either incompletely removed or only biopsied All four patients were alive and well at the time of the report seven months to four years postoperatively Three of the four received roentgen therapy but in only one did thoracic roentgenograms reveal disappearance of the tumor No change was noted in the size of the tumor on thoracic roentgenograms in two cases In addition to these four cases, in two cases reported by Bergstrom the tumors were locally invasive, making a total of six locally invasive hemangiomas of the mediastinum out of 19 reported cases

The value of roentgen therapy in such cases is questionable In only one case in which it was employed did the mass disappear on subsequent thoracic roentgenograms

SUMMARY

A case is reported in which a hemangioma of the mediastinum in a 9 year-old boy was successfully removed at thoracotomy

A total of 19 cases of mediastinal hemangioma have been reported These tumors are commonly located in the anterior mediastinum and should be considered in the differential diagnosis of anterior mediastinal tumors

Complete surgical removal is usually possible but in a significant number of cases the tumor may be locally invasive even though it is a benign tumor that does not metastasize

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SUBCARINAL MEDIASTINAL GRANULOMAS CAUSING ESOPHAGEAL OBSTRUCTION

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DURING the past twelve years, reports of granulomatous lesions of the mediastinum have appeared with increasing frequency pointing to their surgical significance in the differential diagnosis and management of mediastinal tumors. It is the purpose of this paper to report 3 cases of subcarinal mediastinal granulomas causing obstructive esophagopathy, an uncommon clinical entity.

CASE REPORTS

CASE 1.—V. A. H., Minneapolis, Minnesota, No. 154-170. The patient was a 24 year old white male student who was well until March 5, 1954, at which time he noted a rubbing sensation in the right chest anteriorly associated with a nonproductive cough. Four days later he experienced right chest pain and dysphagia. Solid foods were more troublesome than liquids. His cough became productive of clear, thin material. A temperature of 102° F. gradually subsided during a seven day interval.

At a neighboring clinic, a barium swallow showed narrowing in the mid portion of the esophagus as by extrinsic pressure and bronchoscopy showed an area of ulceration in the right main stem bronchus. Esophagoscopy showed no intraluminal pathology. Skin tests for tuberculosis and fungi were reported negative. Esophageal dilatations were performed and the dysphagia subsided. His appetite improved and he regained most of a 10 pound weight loss incurred since the onset of his illness. In the middle of May, right chest pain and dysphagia recurred although not as severely as during the initial episode. Chest pain was aggravated by deep breathing or hard work. He was hospitalized on June 1, 1954.

Past History.—The patient admitted having had German measles, whooping cough, and frequent colds as a child. A tonsillectomy was performed in 1941. A traumatic circumcision was sustained in 1942. Pneumonia occurred in 1951.

Family History.—Noncontributory.

Systemic Review.—The patient admitted to easy fatigue. There was a sensitivity reaction to tetanus toxoid.

Physical Examination.—The patient was well developed and well nourished and did not appear ill. Temperature, 98.6° F.; pulse, 68; blood pressure, 106/66 mm. Hg; height, 5 feet 9 inches; weight, 135 pounds. Complete examination revealed only "shotty" cervical nodes bilaterally.

Laboratory Data.—The hemoglobin was 13.9 Gm.; white blood count, 6,400, normal differential count; sedimentation rate, 42 mm. in one hour; and urinalysis normal. The tuberculin skin test with purified protein derivative first strength was one plus. Histoplasmin skin test was two plus. Coccidioidin and Frei tests were negative. Sputum examinations for acid fast bacilli were negative as were cultures and guinea pig inoculations. X-ray of the chest showed mottled calcifications and an ill defined mass in the subcarinal area (Fig. 1). An esophagram showed definite narrowing for approximately 6 cm. just below the carina

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Fig 1 —Case 1 Lateral planigram showing ill defined mass in subcarinal area Mottled calcification not readily apparent in photograph but seen in x ray (Aug 30 1954)

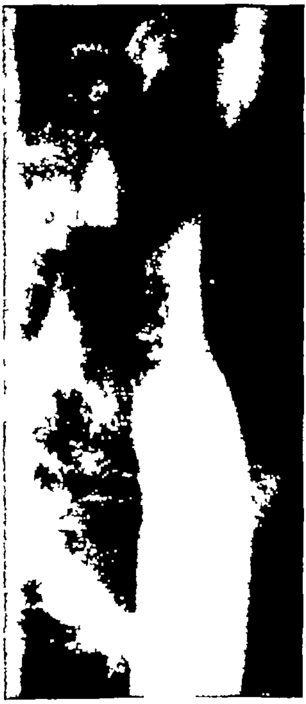

Fig 2

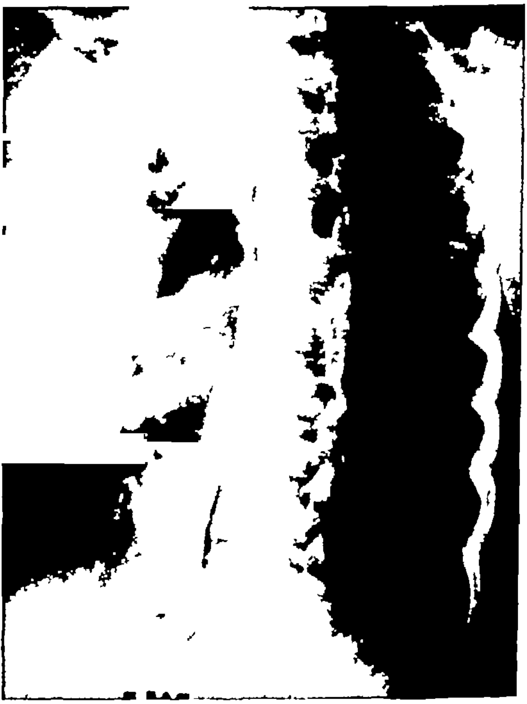

Fig 3

Fig 2 —Case 1 Left anterior oblique projection Barium swallow showing narrowing of the mid-esophagus at subcarinal level (June 3 1953)

Fig 3 —Case 1 Barium swallow spot film showing esophageal defect (Aug 26 1954)

(Figs 2 and 3) There was, however, no obstruction to the flow of barium seen during fluoroscopic study Bronchoscopy performed on June 15, 1954, showed broadening of the carinal area and absence of the carinal spur On the medial aspect of the right main stem bronchus there was a protuberant granulomatous mass 2 by 2 mm which bled easily on contact and from which exuded a thread of thick, creamy material The left main stem bronchus was partially narrowed as by extrinsic pressure The mucosa was thick, shiny, and deeply reddened

Washings of the bronchi submitted for acid fast bacilli and fungi proved negative A biopsy of the mucosa in the carinal area showed subacute and chronic inflammation with several multinucleated giant cells of the Langhans type There was no necrosis and epithelioid cell granulomas were absent

Hospital Course—With the foregoing data, it was felt that this patient had partial esophageal obstruction due to the enlargement of subcarinal lymph nodes Since tuberculosis was considered as a strong possibility in the differential diagnosis, despite the lack of bacteriologic confirmation, chemotherapy was started on June 30, 1954, consisting of streptomycin, 1 Gm., twice weekly, and para aminosalicylic acid, 12 Gm , daily A broncholith was coughed up during the hospital stay

Early in July, the patient's dysphagia disappeared On Sept 10, 1954, bronchoscopy was repeated showing the carina to be sharp and clean The ulcerated area in the right main stem bronchus was still present but was no longer friable or draining The inflammatory changes in the left main stem bronchus were less marked

Because of the persistent bronchoscopic changes suggesting a chronic, smoldering inflammatory process and because of the inability to rule out other mediastinal lesions, thoracotomy was elected

Operative Report—Right thoracotomy was performed on Sept 6, 1954, in the lateral position through the bed of the sixth rib The pleural space was free There was some scarring of the apical pleura but the lung was otherwise free of palpable disease There was a firm mass approximately 6 cm in largest diameter in the subcarinal area, grossly resembling chronically inflamed lymph nodes The mass was densely adherent to the right and left main stem bronchi, to the pericardium and esophagus, compressing the right side of the latter Several peribronchial and inferior mediastinal lymph nodes were noted and were not remarkable

The mediastinal pleura above and below the subcarinal mass was raised allowing mobilization of the esophagus and thus better orientation of the relation of the tumor to the surrounding structures The mass was then sharply dissected from its attachment to the right main stem bronchus, revealing a granular area on the inferior margin approximately 1 cm in diameter suggesting the site of ulceration and eruption into the right main stem bronchus In similar fashion, the mass was excised from its attachments to the pericardium, left main stem bronchus, and esophagus In one area of the esophagus, the submucosa was bared requiring reconstruction of the muscularis A frozen section examination of the resected specimen confirmed the inflammatory nature The chest was closed with drainage The postoperative course was uneventful The patient had no dysphagia three months postoperatively

Pathologic Report—*Gross appearance* (Fig 4, *A* and *B*) The specimen consisted of a mass of tissue which measured 6 5 by 4 by 2 cm It was slightly irregular and had a smooth fibrous surface except in one area where there was a groove measuring 3 by 2 cm with a rough hemorrhagic base in which there were studded many fine white dots On cut surface, the mass had a fibrous capsule from which there were numerous fibrous trabeculae coursing through the interior and between which were small areas of soft, tan tissue, and nodules consisting of pale, yellowish white, pasty material measuring 8 mm in greatest diameter *Microscopic examination* (Fig 5, *A* and *B*) The mass consisted of a fibrous and lymphatic tissue background in which there were numerous epithelioid granulomas, many of which contained necrotic centers and numerous multinucleated giant cells A multinucleated cell was present which contained a Schaumann's body Foci of calcification were also noted. Acid fast and fungus stains failed to reveal any organisms

Diagnosis—Granulomatous inflammation of the mediastinal lymph nodes, probably tuberculosis

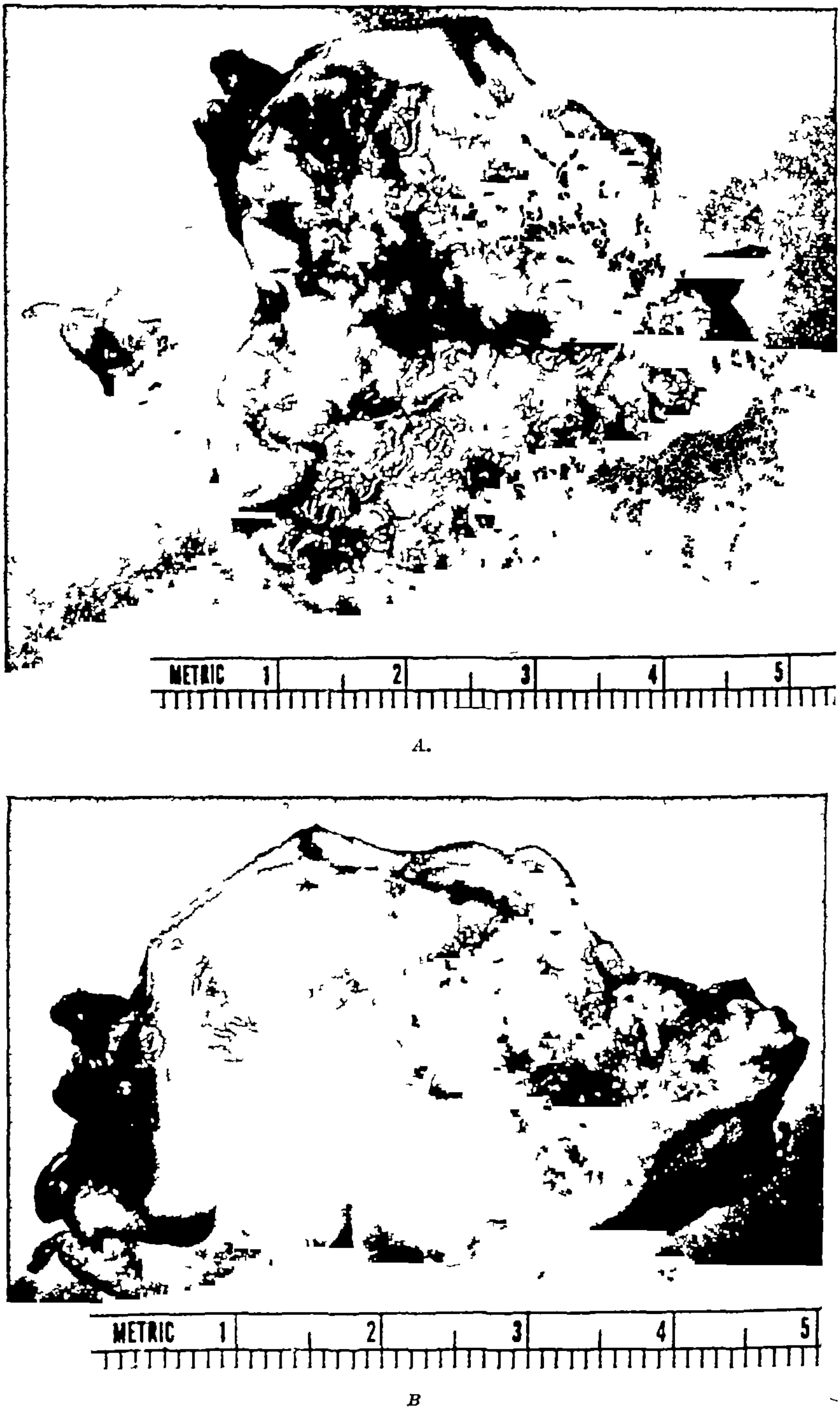

Fig 4 —Case 1 *A* Gross specimen as removed *B* Gross specimen in cross section

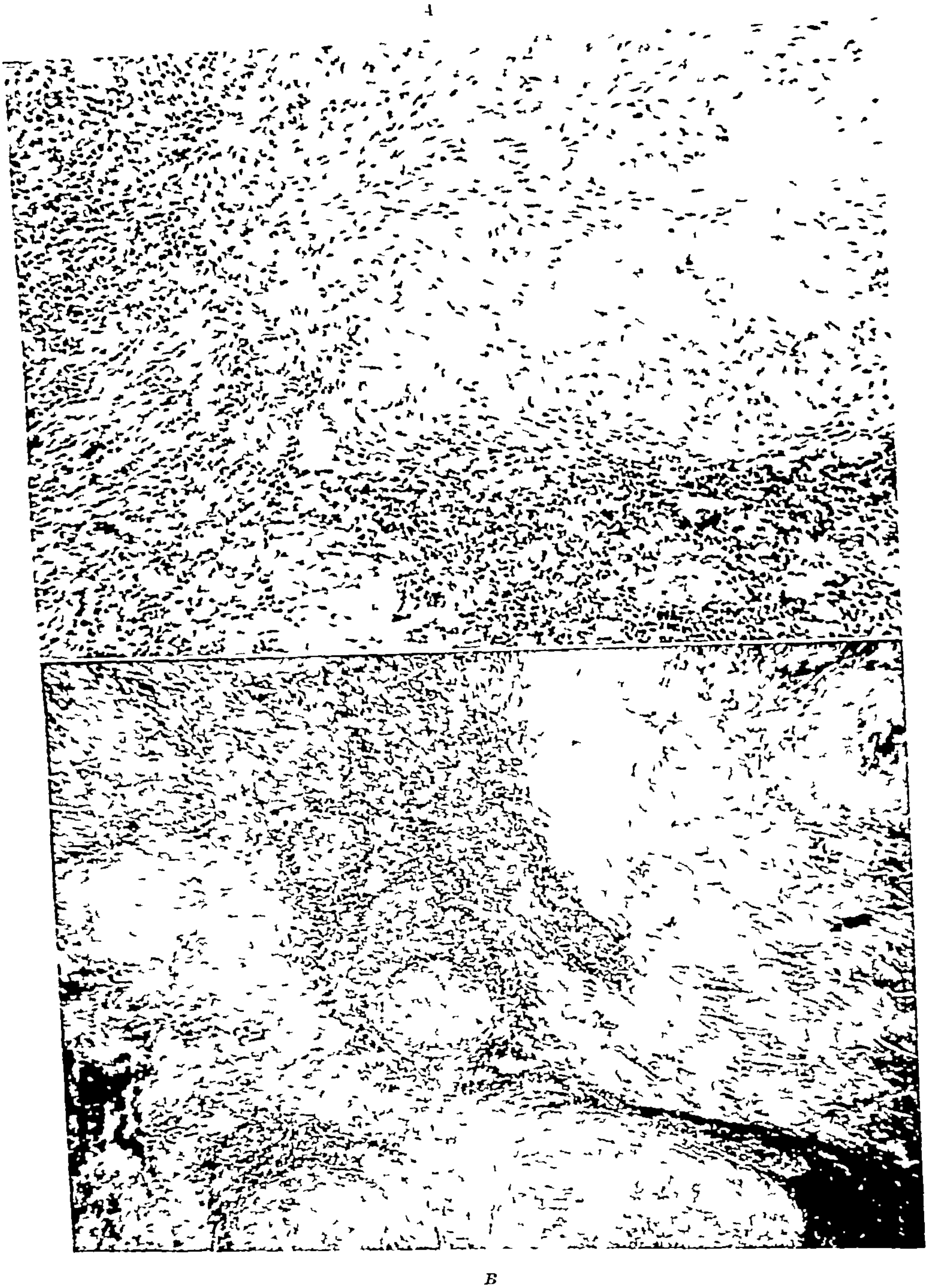

Fig 5.—Case 1 *A* Photomicrograph showing a large granuloma with a caseous center and epithelioid zone present in the right upper quadrant. Multinucleated Langhans-type giant cells are noted on the periphery of the granuloma (×100 reduced ¼) *B* Photomicrograph showing multiple epithelioid granulomas with central areas of necrosis Large zones of fibrosis are apparent. (×36 reduced ¼)

CASE 2 —St Mary's Hospital, Minneapolis, Minnesota, No 218144 A 39 year old white housewife was hospitalized on March 25, 1954, complaining of dysphagia of ten weeks' duration commencing with liquids and progressing to solid foods She also noted weakness and frequent regurgitation For one week she experienced severe odynophagia and regurgitated all ingested food Forty eight hours prior to admission she refused all foods

Past History —Hypothyroidism followed a thyroidectomy done in 1948 Appendectomy and bilateral tubal ligation were previously performed

Family History —Diabetes mellitus and tuberculosis were elicited

Systemic Review —Noncontributory

Physical Examination —The temperature was 98 6° F , pulse 76, blood pressure, 120/70 mm Hg The patient was well developed, well nourished, and appeared in a mild state of anxiety The general physical examination was otherwise not remarkable

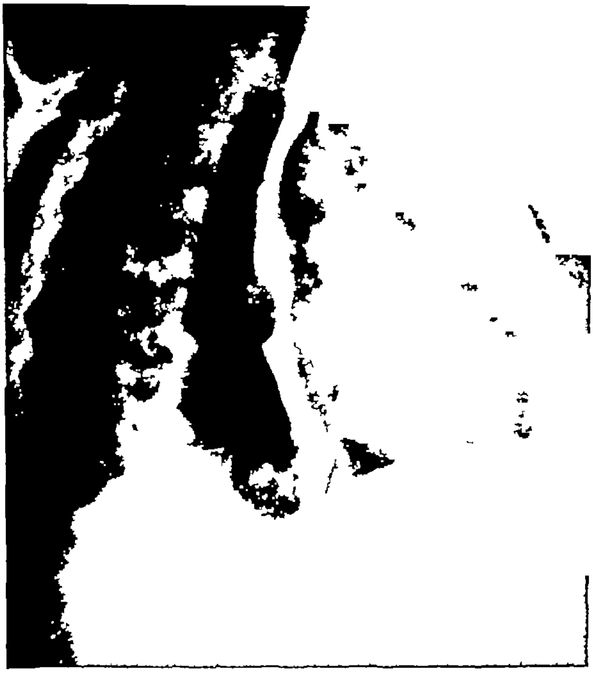

Fig 6 —Case 2 Right anterior oblique projection Barium swallow showing filling defect of esophagus in the mid-portion suggesting an extrinsic lesion. (April 23 1954)

Laboratory Data —The urinalysis was negative, hemoglobin, 11 4 Gm , white blood count 8,100 Routine x ray of the chest was negative A barium swallow showed a filling defect of the esophagus in the mid portion suggesting an extrinsic lesion (Fig 6)

Hospital Course —Esophagoscopy failed to reveal an intrinsic lesion There was definite fullness on the posterior wall of the esophagus, 27 cm from the incisor teeth An extrinsic tumor mass was noted on the posterior and right lateral wall The esophagoscope was not advanced beyond the tumor level Aspiration studies for tumor cells and acid fast organisms were negative On March 26, 1954, thoracotomy was performed

Operative Report —The right pleural space was free In the tip of the middle lobe anteriorly, there was a "shotty" area of granulomatous infiltration characteristic of old stabilized tuberculosis The pleura was adherent to the tumor which was palpable between the right main bronchus and the esophagus and extended down along the posterior aspect of the intermediate bronchus The lower pole of the tumor penetrated the esophageal wall and was also densely adherent to the vagus nerve bronchus, and surrounding structures Frozen section study of a portion of the mass disclosed inflammatory changes The tumor was dissected from the esophagus the muscularis being removed to the submucosa. Many pockets of purulent material were encountered in the granulomatous tumor mass These were aspirated and reserved for culture and microscopic examination The muscular defect in the esophagus was repaired The infiltration in the tip of the middle lobe was removed by clamp resection and the chest was closed with catheter drainage

Pathologic Report—*Gross appearance* The specimen consisted of three lymph nodes, the largest of which measured 5 by 2 5 by 2 5 cm On gross examination there were numerous areas of yellowish necrosis A segment of pulmonary parenchyma measuring 3 by 2 by 1 cm showed on gross examination multiple areas of necrosis up to 1 5 cm in diameter *Microscopic examination* (Fig 7) Sections of the lung and lymph nodes revealed the presence of large and small granulomas The smaller ones were composed entirely of epithelioid cells and the larger ones showed central necrosis There were also noted scattered Langhans type giant cells Stains for acid fast organisms were negative Cultural studies for acid fast organisms and fungi were negative

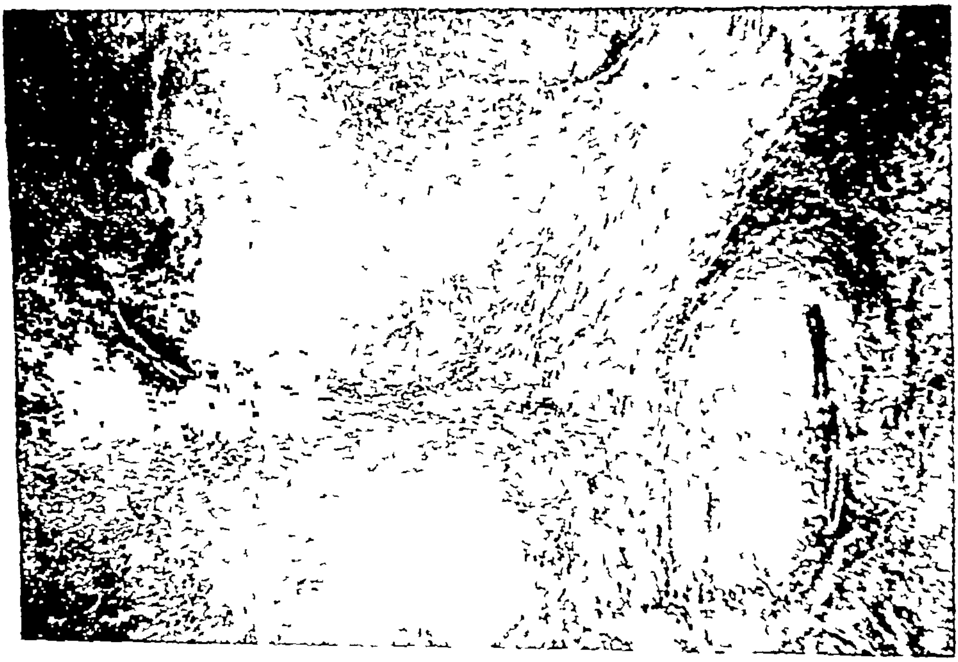

Fig 7—Case 2 Photomicrograph showing multiple granulomas with central necrosis surrounded by palisaded histiocytes and epithelioid cells (×36 reduced ¼)

Diagnosis—Pulmonary and lymph node granulomas of undetermined etiology

Postoperative Course—The immediate convalescence was uneventful Because of the indeterminate nature of the lesion and the possibility of tuberculosis, PAS and streptomycin were administered Four months postoperatively the patient had no dysphagia One month later she was nervous and was having tightness on swallowing Three dilatations were performed Six months postoperatively on the last visit, there was no dysphagia but she complained of pain in the epigastrium about ten minutes after eating

CASE 3—University of Minnesota Hospital, No 851804. The patient was a 25 year old male physician who was well until April 7, 1953, when he developed a sore throat He treated himself with Aureomycin and a 250 mg Aureomycin capsule lodged in his esophagus He felt as though his esophagus went into spasm Subsequently for thirteen days he had further dysphagia but did experience slight odynophagia especially if his food was lumpy On April 20, 1953, a piece of beefsteak stuck in his esophagus and he subjectively localized the obstruction near the mid esophagus A similar episode occurred on April 24, 1953, and during the night of April 26, 1953, he was awakened with spasmodic esophageal pain He consulted his physician on April 27, 1953

Past History —The patient had frequent episodes of severe sore throat with *Streptococcus viridans* as the causative organism His tonsils had been hypertrophic since early childhood

Family History —Noncontributory

Systemic Review —Noncontributory

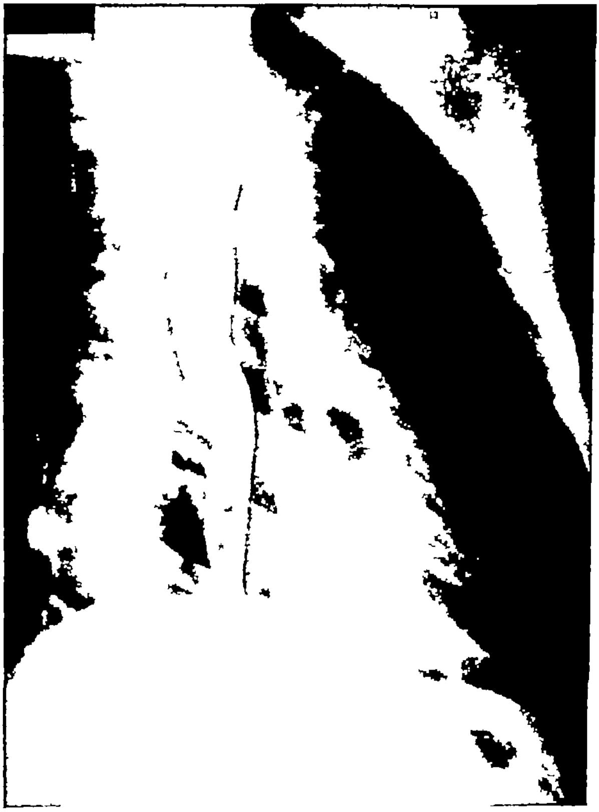

Fig 8 —Case 3 Right anterior oblique projection Barium swallow showing esophageal defect and displacement of the esophagus to the left.

Physical Examination —The patient was a well developed, well nourished individual who showed no evidence of chronic illness The temperature was 100° F , pulse 88, and blood pressure, 135/80 The only gross abnormal physical finding was the presence of large, soft, furrowed tonsils which were inflamed

Laboratory Data —The hemoglobin was 14.1 Gm , white blood count 9,850, neutrophils 83 per cent, lymphocytes 14 per cent, monocytes, 3 per cent The sedimentation rate was 73 mm in one hour The urinalysis was normal Tuberculin skin test with second strength PPD was negative Sputum studies for acid fast bacilli were negative Histoplasmin skin test 1 1,000 was negative Peripheral blood smear showed no evidence of leukemia Roentgenologic examination of the chest in the posteroanterior position showed a mass in the mid mediastinal area extending to the right side The mass was of indeterminate character, and on lateral projection the mass occupied the middle of the posterior mediastinum

An esophagram revealed a large mass attached to the right posterior portion of the esophagus, displacing the esophagus to the left It appeared to be extraluminal but intramural (Fig 8)

A preoperative diagnosis of intramural esophageal mass, either leiomyosarcoma or leiomyoma, was made

Operative Report—On May 1, 1953, right thoracotomy was performed in the lateral position through the bed of the fifth rib The pleural space was free There was no palpable disease in the lung parenchyma A firm mass, 7 by 5 by 3 5 cm, was present in the subcarinal area displacing the esophagus and right lower lobe bronchus The esophagus and right lower lobe bronchus were bent over this tumor The mass was excised from these structures to which it was adherent The chest was closed with drainage

Pathologic Report—*Gross appearance* The specimen was an irregular mass of firm tissue 7 by 5 7 by 3 5 cm which seemed to consist of enlarged lymph nodes On sectioning, large areas of grayish, white, caseous material measuring up to 1 5 cm were noted

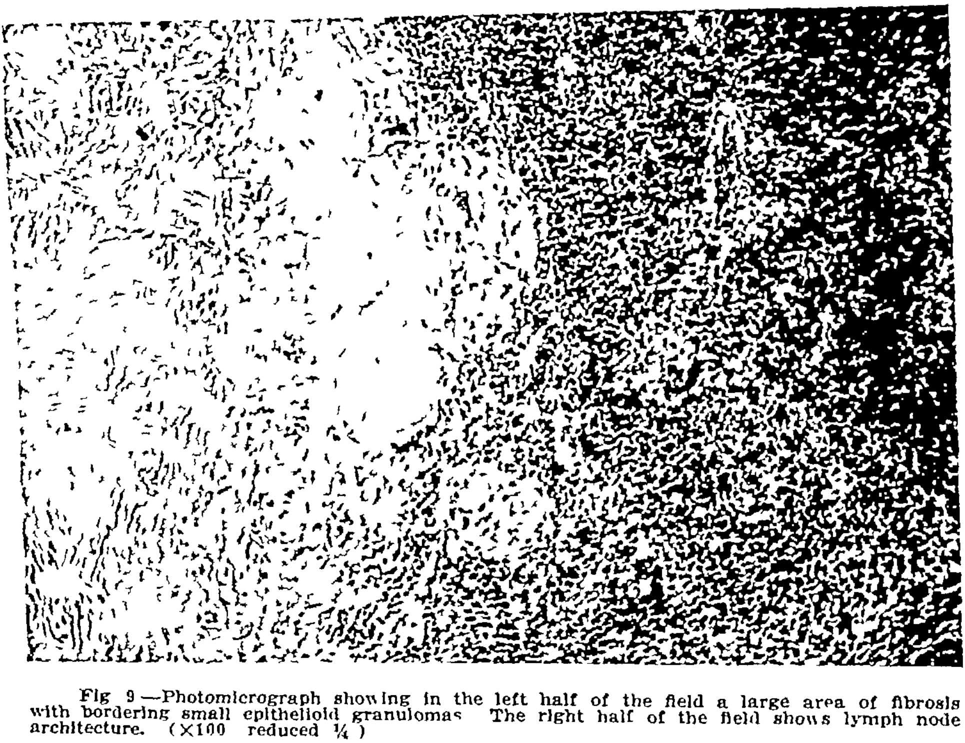

Fig 9—Photomicrograph showing in the left half of the field a large area of fibrosis with bordering small epithelioid granulomas The right half of the field shows lymph node architecture. (×100 reduced ¼)

Microscopic Appearance—(Fig 9) Microscopically, portions of lymph nodes were seen with large areas of necrotic, granular, pink staining material surrounded by epithelioid cells and a few multinucleated giant cells Many polymorphonuclear and mononuclear inflammatory cells were seen. The surrounding tissue showed an increased amount of fibrous tissue and carbon pigment Some calcific material was present in necrotic areas No tubercle bacilli were seen with special staining techniques The appearance of the specimen was compatible with tuberculosis or similar granulomatous processes

Diagnosis—Chronic granulomatous inflammation of mediastinal lymph nodes

Postoperative Course—Postoperatively the patient developed partial atelectasis of the right lung which cleared with intratracheal suctioning Eighteen months postoperatively there were no esophageal symptoms

TABLE I

CASE NO	REPORTED BY	AGE	SEX	SYMPTOMS	MEDIASTINAL LOCATION	TUBERCULIN SKIN TEST	OTHER SKIN TESTS	PREOPERATIVE DIAGNOSIS	ACID FAST BACILLI
1	Grace[1]	32	F	Dyspnea, pain, cough	Left anterior superior hilar	Positive	Not reported	Dermoid	None
2	Blades and Dugan[5]	56	M	Dyspnea	Right posterior inferior	Not reported	Not reported	Neurogenic tumor	Acid fast rare
3	Tjamouranis[6]	5	F	Dyspnea, cough, stridor	Right superior	Positive	Casoni, negative	Tuberculoma	None
4	Paulson[7]	33	M	None	Right posterior superior	Positive	Not reported	Mediastinal tumor	None
5	Paulson[7]	21	M	None	Right posterior superior	Positive	Not reported	Mediastinal tumor	None
6	Perasalo[8]	16	F	Tiredness, weakness, anemia, vague pressure	Right posterior superior	Positive	Not reported	Mediastinal cyst	Not reported
7	Case report, M G H 1945[9]	43	F	Substernal pain, dysphagia	Level of carina	Not reported	Not reported	Carcinoma, esophagus	Not reported
8	Samson, Heaton, and Dugan[10]	27	F	Dysphagia	Right posterior superior	Not done	Not done	Dermoid	None
9	Samson, Heaton, and Dugan[10]	19	M	None	Left anterior superior	Negative	Coccidioidin, negative	Dermoid	None
10	Samson, Heaton, and Dugan[10]	22	M	Dyspnea, cough	Left anterior superior	Not done	Not done	Bronchogenic cyst	None

11	Samson, Heaton, and Dugan[10]	34	F	Severe cough, dyspnea	Right posterior superior	Positive	Coccidioidin, negative, histoplasmin, positive	Mediastinal tumor ? aneurysm	None
12	Samson and Dugan[11]	29	F	Pain, dysphagia, odynophagia	Subcarinal	Not reported	Not reported	Hiatus hernia	Few on direct smear
13	Goldman[12]	Not reported			Bifurcation of trachea	Negative	Coccidioidin, negative	Carcinoma esophagus	Not reported
14	Woodruff[13]	60	M	Not reported	Bifurcation of trachea	Not reported	Not reported	Not reported	Not reported
15	Storey and Lyons[14]	24	M	None	Right superior	Positive	Negative	Not reported	Present
16	Storey and Lyons[14]	20	M	None	Anterior cardiophrenic angle	Negative	Not reported	Echinococcus cyst, pericardial cyst, atelectasis	None
17	Storey and Lyons[14]	25	M	None	Right posterior	Negative	Negative	Tuberculoma	Present
18	Storey and Lyons[14]	20	M	Headache, malaise, anorexia, cough, expectoration	Right superior	Negative	Negative	Tuberculoma	None
19	Storey and Lyons[14]	30	M	Pain in shoulder, arm, chest, venous obstruction	Right superior	Positive	Negative	Boeck's sarcoid, Hodgkin's disease, tuberculosis, lymphoblastoma	None
20	Rapant and Dvoracek[15]	19	M	Paravertebra, interscapular pain, cough	Posterior superior mediastinum	Negative	Not done	Neurogenic tumor	None

TABLE I—CONT'D

CASE NO	REPORTED BY	AGE	SEX	SYMPTOMS	MEDIASTINAL LOCATION	TUBERCULIN SKIN TEST	OTHER SKIN TESTS	PREOPERATIVE DIAGNOSIS	ACID FAST BACILLI
21 36	Kunkel, Clagett, and McDonald[10] (16 cases)	2 59 years	8 M 8 F	10 Asymptomatic referable to chest 3 Minimal symptoms (Above 13 cases noted on routine x ray of chest) 1 Pleuritic pain, fever, weight loss 1 Fever, substernal heaviness, dyspnea 1 Wheezing, cough, fever	13 Right paratracheal 1 Paratracheal, bilaterally 1 Left hilus 1 Left posterior inferior	6 Negative 2 Positive	3 Negative	Not given for individual cases Differential diagnosis included Granuloma Thymoma Dermoid cyst Enterogenous cyst Thyroid adenoma Lymphoma Neurogenic tumor Aneurysm Other rare conditions	12 smears, negative 13 guinea pigs and cultures, negative
37	Authors	24	M	Chest pain, cough, fever, dysphagia	Subcarinal	Positive	Negative	Mediastinal granuloma	None
38	Authors	39	F	Severe dysphagia, odynophagia, regurgitation	Subcarinal	Not done	Not done	Esophageal tumor, stricture	None
39	Authors	25	M	Sore throat, dysphagia, odynophagia	Subcarinal	Negative	Histoplasmin, negative	Intramural tumor of esophagus	None

DISCUSSION

Piazzi-Martinni[1] described cases of mediastinal tuberculoma and gumma Haines[2] recognized the development of mediastinal tumefaction due to lymph node enlargement in the course of systemic tuberculosis or syphilis and also mentioned the necessity of differentiating these tumors from other new growths Grow[3] and his associates reported 8 cases of tuberculous lymphadenopathy in 73 cases explored for mediastinal lesions Additional details were lacking Grace[4] is credited with the first surgical extirpation of a mediastinal granuloma and others have since reported cases treated surgically These are summarized in tabular form (Table I)

Analysis from the available information in the 39 collected cases surgically treated including 3 of this report reveals the following data (Table II)

Other similar cases not treated by surgical excision have been reported by Perasälo[5] and Storey [14] Paulson commented on 2 additional cases under ob

TABLE II

Age	2 60 years
Sex	16 females 22 males 1 not recorded
Symptoms	16 asymptomatic 6 dyspnea 8 cough 7 chest pain 6 dysphagia 3 odynophagia 4 fever 4 others 2 not reported
Mediastinal location	19 right posterior superior 5 right superior 1 right posterior inferior 3 left anterior superior 1 left posterior inferior 1 right and left superior posterior 1 left hilus 1 anterior cardiophrenic angle 1 level of carina 6 subcarinal
Tuberculin skin test	11 positive 13 negative 3 not done 12 not reported
Other skin tests	12 negative 1 positive 4 not done 22 not reported
Preoperative diagnosis	2 correct 2 probably correct correct in others (cases 21 26) number correct not given
Acid fast bacilli	4 positive 28 negative 7 not reported

servation, 1 asymptomatic and 1 with dysphagia, both with presumptive diagnoses of tuberculoma Frew[17] reported a case of esophageal and tracheal obstruction at the postcarinal level Biopsy through intact esophageal mucosa showed a histologic pattern typical of tuberculosis Bacteriologic confirmation was lacking Clerf[18] reported a case of a 22-year-old seminarian with dysphagia and odynophagia The esophagus was narrowed at the level of the aortic arch and displaced anteriorly The mucosa was inflamed Purulent drainage was promoted by instrumentation Bacteriologic studies showed tubercle bacilli, a few pneumococci, and streptococci The source of infection was presumed to be tuberculosis of the mediastinal nodes Jacob[19] presented a case of a 28 year-old woman with esophageal obstruction at the level of the aortic arch Acid fast bacilli were recovered from a subclavicular node Radiotherapy to the mediastinal nodes rendered a good result

COMMENT

Although the etiology of practically all of these mediastinal lesions remains indeterminate with our present methods of investigation, the probable relation to tuberculosis warrants continued attention This aspect of the problem is of more than academic interest in view of the beneficial effects of antimicrobial drug therapy in tuberculosis In earlier reports of tuberculosis involving the esophagus, the process had advanced in most instances to the stage of ulceration, perforation, or fistulization with the trachea or bronchi Denonnvilliers[20] reported the first case in 1837 Flexner[21] discussed the pathogenesis, emphasizing the different routes of infection Lockhard[22] reviewed the literature and collected 103 cases, 69 of which could with reasonable certainty be classified as tuberculous In his study, extension by continuity from caseous bronchial glands was by far the most frequent etiological factor accounting for 35 of 103 cases studied Although the etiology of the cases herein reported by us has not been confirmed by bacteriologic studies, it is suggested that the location of the granulomatous lesions, the histopathologic characteristics, the resemblance to similar cases cited in which the bacteriologic studies confirmed the diagnosis of tuberculosis, are not coincidental It is, nevertheless, agreed that the term tuberculoma should be reserved only for those cases in which specific acid-fast organisms are found

Admittedly uncommon, at least 6 and probably 2 others (Cases 13 and 14) of the collected cases surgically treated, presented with symptoms referable to the esophagus and, therefore, mediastinal granulomas should be considered in the differential diagnosis of obstructive lesions of the esophagus A sufficient number of granulomas have been reported to assign them a rightful niche in the classification of mediastinal tumefactions and they are therefore worthy of attention in managing indeterminate mediastinal lesions

Although no particular technical surgical problems were encountered in the 3 cases reported, these have been mentioned by others (Samson and associates,[10] Storey,[14] Kunkel[16]), particularly in dealing with lesions related to large vessels This is consonant with the character of the underlying pathology The sequelae of tracheal, bronchial, and esophageal and vascular obstruction in given instances establish mediastinal granulomas as potentially hazardous lesions The serious consequences of mediastinal fibrosis presumably of granulomatous origin are well illustrated by a case cited by Kunkel[16] in which there was tracheal and bronchial obstruction and also by the fascinating case of Edwards and Burchell[23] in which the venous return from both lungs was completely occluded except for the right inferior pulmonary vein, with resultant pulmonary hypertension, ventricular failure, and death It is felt that symptomatic and doubtful lesions present definite indications for surgery

SUMMARY

1 Three uncommon cases of subcarinal mediastinal granulomas producing esophageal obstruction are presented

2 Previously reported cases of mediastinal granulomas surgically treated are reviewed.

3 The etiology of most of these lesions remains challenging but the probable tuberculous origin demands continued special attention

4 Symptomatic and doubtful lésions are definite indications for surgery

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SURGICAL TREATMENT OF PULMONARY TUBERCULOSIS IN AN ISOLATED SANATORIUM

A Five-Year Study of Trends and Results

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Ninette, Manitoba

INTRODUCTION

DURING the earlier days of this century when bed rest, fresh air, and seclusion rated high as treatment for tuberculosis, *many sanatoriums* were located in isolated areas In keeping with this trend, Manitoba Sanatorium was built in scenic surroundings in 1909, about 150 miles from the chief medical and population center of the Province With the widespread adoption of surgical collapse in the mid-thirties many such institutions met the problem of major chest surgery, either by sending their patients for operation to the nearest large center, or by having a consultant surgeon come in periodically to do the work Less frequently the sanatorium setup a self-contained surgical unit with all operations performed by the resident medical staff In support of this plan, Ross[1] in 1937 discussed the advantages of a sanatorium doing its own surgery, a policy which Manitoba Sanatorium adopted at that time and has adhered to ever since

The plan succeeded well from the first Meltzer,[2, 3, 4] who was resident surgeon from 1936 to 1941, published results in thoracoplasty and extrapleural paraffin plombage which compared very favorably with those obtained elsewhere Since 1941, I, *as resident surgeon, have performed all the operations* on patients of this institution The problems of a Sanatorium doing its own surgery have multiplied in recent years for this 280 bed hospital Isolation is the prime obstacle The universal nursing shortage, worse in a sanatorium because of tuberculophobia, is further accentuated by our distance from larger centers At first, anesthesia gave no special concern, because in the collapse therapy era we used a local anesthetic for all chest wall operations Later, with the increasing need of pulmonary resection, the lack of a resident anesthesiologist was a serious handicap, and necessitated bringing one in for each such operation Early in 1953, the problem of anesthesia was solved by training one of our own staff and since then the use of resection has markedly increased

At times we have seriously questioned the merit of keeping up our surgical service under existing difficulties Nowadays, patients, as well as staff,

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From The Manitoba Sanatorium Ninette Manitoba
Received for publication Jan 27 1955

tend to shun isolation with its fewer leaves and visits from families and friends. However our very isolation has paradoxically been the best reason for continuing. An institution if associated in the public mind with modern surgical treatment will attract both patients and staff and partly offset the objections of isolation. In other matters we are well set up for surgery. Laboratory facilities are excellent; blood is immediately available in any quantity and without charge through the Provincial Red Cross. All surgical specimens are carefully dissected out by the surgeon following operation; smears are taken for direct examination for tubercle bacilli and for culture. The specimen is then photographed in color and sent away for gross and microscopic pathological examination.

These circumstances under which the surgery to be reported was done have been outlined to serve as a background for better appraisal of the methods used and results obtained. That the surgery was performed at the Sanatorium by a resident staff under a considerable handicap imposed by isolation may actually add interest to the series and it is believed has not adversely affected the results of treatment herewith presented.

MATERIAL

A list of all major surgical operations done during the five-year study period from Jan. 1, 1949 to Jan. 1, 1954 is given in Table I. Numbers refer to how often the procedure was performed and not to individuals treated. In some instances patients had more than one procedure on the same side, as in resection following failure of thoracoplasty; in other cases bilateral surgery was done. The thoracoplasty listing includes 8 operations to obliterate pleural space before or after resection and 3 for treatment of empyema. Thus Table I presents the total amount of surgery done in the five-year period but does not lend itself to an analysis of results.

TABLE I. COMPLETE LIST OF SURGICAL PROBLEMS*

PROCEDURE	NUMBER OF TIMES USED
Thoracoplasty (completed operations, not stages)	141
Revision thoracoplasty	8
Extraperiosteal plombage	21
Pulmonary resection	89
Decortication	3
Cavernostomy	5
Extrapleural pneumothorax	1
TOTAL	268

*Manitoba Sanatorium, Jan. 1, 1949 to Jan. 1, 1954.

For purposes of analysis, the study has been confined to 219 patients who received major surgical treatment of parenchymal disease only. Of these 194 patients had unilateral surgery; 25 patients had bilateral surgery, 9 of whom had both sides operated upon during the five-year study period and 16 of whom had one side completed before the study began. All patients received some antibiotic therapy. The earlier cases often had only a few days of streptomycin during operation, although a six weeks' course of 0.5 Gm. daily was not uncommon in 1949. Later, combined antibiotic therapy became routine practice with the treatment period steadily increasing.

DEFINITION OF TERMS

In classifying results of treatment, "negative sputum" means sputum negative to smear, concentrate, and culture of gastric contents. Patients taking discharge too soon to allow complete sputum testing are considered positive until proved otherwise by further sputum examination. "Primary conversion" refers to sputum rendered negative by the first surgical procedure and "secondary conversion" refers to sputum becoming negative after a further surgical procedure.

Postoperative deaths or complications are those occurring within sixty days of operation, those after this period are termed "late." The final date for evaluation of status was placed at July 1, 1954, thus giving a follow-up period of six months for all cases and a maximum follow-up of five and one-half years.

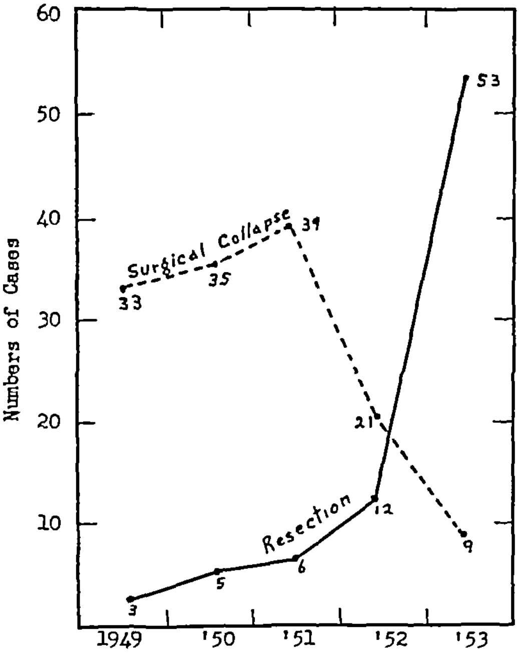

Fig. 1

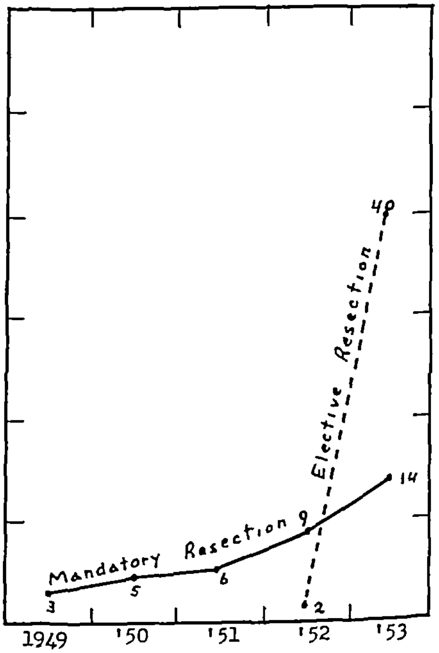

Fig. 2

Fig. 1.—Graph showing the changing incidence of surgical collapse and pulmonary resection.

Fig. 2.—Graph showing the incidence of mandatory and elective resections.

Follow-up Classification.—Almost all patients after discharge obtain their periodic examinations by returning to the Sanatorium or attending stationary or travelling clinics operated by the Sanatorium Board. This gives greater accuracy in roentgenographic interpretation and estimation of stability of disease than one could expect from reports of local physicians Living patients are classified under four commonly accepted headings as follows

1 Clinically well with negative sputum,
2 Positive sputum or unstable roentgenogram (salvable cases)
3 Active or progressive disease or respiratory cripple (hopeless cases),
4 Inadequate follow-up—those where most recent report is before December, 1953 and/or less than six months postoperatively

ANALYSIS

Unilateral Surgery—As stated before, 194 patients had unilateral surgery, 137 received collapse therapy as a primary procedure and of these, 22 also underwent resection before the end of the study period in addition, 57 other patients in the unilateral group had resection which makes a total of 79 resections for analysis The various procedures employed with their yearly incidence are shown in Table II It will be seen that the number of patients with collapse therapy dropped from 33 in 1949 to 9 in 1953 while those treated by resection rose in the same period from 3 to 53 As elsewhere antibiotic therapy is the chief factor in this reversal of incidence However the trend toward resection came later than usual in the present series due to the lack of resident anesthetic service in the early years of the study In 1953, when this service was established, there was a marked upswing in resection surgery with a corresponding drop in collapse surgery as graphically illustrated in Fig 1 A point of special interest is the increased use of apical, or 5 rib thoracoplasty toward the middle of the study period, as seen in Table II Rapid clearing of disease with antibiotic therapy permitted the use of this less extensive thoracoplasty with increasing frequency It was often applied as collapse treatment of residual foci in place of removal by resection as we are now doing Usually cavitation, if present, had been greatly reduced Our interest in extraperiosteal pack did not develop until 1951, so the place of this procedure was partly taken by apical thoracoplasty

TABLE II UNILATERAL SURGERY 1949 TO 1953—216 CASES

PROCEDURE	NUMBER EACH YEAR					TOTAL
	1949	1950	1951	1952	1953	
Collapse Therapy						
Standard thoracoplasty	25	24	17	9	2	77
Apical thoracoplasty	6	10	13	7	3	39
Revision thoracoplasty	2	1	4	1	–	8
Extraperiosteal plombage	–	–	5	4	4	13
TOTAL	33	35	39	21	9	137
Resection						
Pneumonectomy	1	5	2	4	2	14
Lobectomy	2	0	4	5	8	19
Lobectomy plus	–	–	–	1	8	9
Other multiple resection	–	–	–	–	5	5
Wedge resection	–	–	–	–	22	22
Segmental resection	–	–	–	1	6	7
Lesionectomy	–	–	–	1	2	3
TOTAL	3	5	6	12	53	79

The use of further secondary surgery in the various collapse groups was as follows of 77 patients with standard thoracoplasty, 14 had resection, and 2 cavernostomy, of 39 patients with apical thoracoplasty, 4 had resection, and 2 cavernostomy, 2 of the 13 patients with extraperiosteal pack had resection later, as did also 2 of 8 patients with revision thoracoplasty Thus, of the whole group of 137 patients with unilateral surgical collapse, 22 ultimately had resection, and 4 cavernostomy

As regards resection surgery, it will be noted in Table II that it was almost entirely confined to pneumonectomy and lobectomy during the first four years of the study period During this period, resection was done mainly on thoracoplasty failures and only when no alternative collapse measure would suffice The marked increase in resection in the last year of the study was due mainly to its more frequent use as an elective procedure as seen in Fig 2

Indications for unilateral resection are outlined in Tables III and IV In 37 patients, resection was mandatory, according to commonly accepted treatment standards These indications are listed in Table III and require no comment, except to point out that thoracoplasty failure was the most common

TABLE III INDICATIONS FOR UNILATERAL RESECTION, MANDATORY IN 37 CASES

Thoracoplasty failure	21
Endobronchial disease with stenosis atelectasis or sepsis	6
Bronchopleural fistula and empyema	1
Bilateral tuberculosis with low pulmonary reserve	3
Basal or hilar tuberculosis	5
Tuberculosis plus bronchiectasis	1
TOTAL	37

Also, it should be explained that the indication listed as "bilateral tuberculosis with low pulmonary reserve" refers to patients with bilateral lesions of such extent and location that surgical collapse was thought likely to encroach too much on pulmonary reserve In these 3 cases, bilateral resection was thought to be necessary sooner or later In 42 patients, resection was considered an "elective" procedure (Table IV) In all elective cases, disease was in the upper lung field and the patient had had antibiotic therapy for an average of six months The treatment of the residual disease presented a problem on which there is, of course, no agreement at the present time In some instances, such as those with open cavity and positive sputum, the need for surgery is granted but collapse could be used rather than resection In other cases, as in noncavitary disease with negative sputum, the alternative treatment may be prolonged antibiotic therapy without surgery Table IV attempts to list the various combinations of roentgenographic and sputum status found in the "elective" group and correlates these with the bacillary findings in the operative specimens In Series I (8 cases) are patients with either open cavity or persistent positive sputum, or both, and who would commonly be considered for some form of surgery In this group 87 per cent of the operative specimens showed tubercle bacilli on smear and 37 per cent on culture Series II (34 cases) consists of patients who originally had no roentgenographic evidence of cavity and no positive sputum or with cavity closed and sputum converted by antibiotic treatment Some of these patients might be considered suitable for prolonged antibiotic therapy without surgery, but all had residual foci considered "significant" and more than a centimeter in diameter Also, the operative specimens all showed caseation with 62 per cent positive for tubercle bacilli to smear and 14 per cent to culture Attention is called to the 10 cases in the noncavitary always negative group in Series II Of these, 5, or 50 per cent were tuberculomas all showed tubercle bacilli on smear of the operative specimen, 2 were positive to culture

TABLE IV INDICATIONS FOR UNILATERAL RESECTION ELECTIVE IN 42 CASES

	NUMBER	OPERATIVE SPECIMEN	
		SMEAR POS	CULTURE POS
SERIES I			
Preoperative Status			
Cavity open sputum positive	5	5	2
Cavity open sputum converted	1	1	0
Cavity closed sputum positive	1	1	1
Noncavitary, sputum positive	1	0	0
TOTAL	8	7 (87%)	3 (37%)
SERIES II			
Preoperative Status			
Cavity closed, sputum converted	10	6	1
Noncavitary, sputum converted	14	9	2
Noncavitary, always negative	10	6	2
TOTAL	34	21 (62%)	5 (14%)

RESULTS IN UNILATERAL COLLAPSE THERAPY

All significant data are given in Table V which is self-explanatory, but some details are worth comment The highest incidence of sputum conversion of those alive and well is in apical thoracoplasty This is to be expected in view of the lesser extent of disease being treated Even so, 6 of these 38 patients with final conversion became negative only by virtue of secondary operations

The final conversion rate for the entire group of 137 with unilateral collapse was 84 per cent of which 67 per cent came with the first operation and 17 per cent from secondary procedures The incidence of tuberculous postoperative complications is believed to be unusually low Only 3 patients (2 2 per cent) had a postoperative complication Of these 2 patients had a transitory cardiac decompensation with good recovery and 1 developed atelectasis requiring bronchoscopy before recovery The absence of wound infections and postoperative spreads is worthy of note Late complications occurred in 8 patients (6 per cent) in 3 of these a tuberculous tracheobronchitis ultimately developed considered to be aggravated by the collapse Of the other 5 the late complication consisted of relapse after discharge in 4 and in 1 patient the disease continued to progress in spite of surgery

TABLE V RESULTS IN UNILATERAL SURGERY—COLLAPSE THERAPY

NUMBER OF CASES	THORACOPLASTY						EXTRA PERIOSTEAL PACK		REVISION		TOTALS	
	STANDARD		APICAL		TOTAL							
	NO	%	NO	%	NO	%	NO	%	NO	%	NO	%
	77		39		116		13		8		137	
Sputum conversion												
Primary	46	60	32	82	78	67	9	69	5	62	92	67
Secondary	13	17	6	15	19	16	2	15	2	25	23	17
Final	59	77	38	97	97	83	11	84	7	87	115	84
Tuberculous complications												
Postoperative	2	26	0		2	1 7	0		1	12 5	3	2 2
Late	7	26	1	2 5	8	7	0		0		8	6
Deaths												
Postoperative	0		0		0		0		0		0	
Late	7	9	0		7	6	0		0		7	5
Living (July, 1954)	70	91	39	100	109	94	13	100	8	100	130	95
Well with sputum negative	56	80	35	90	91	84	11	84	5	62 5	107	82
Salvable	6	8	2	5	8	7	1	8	1	12 5	10	8 5
Hopelessly ill	2	3	1	2 5	3	3	0		0		3	2
Inadequate follow up	6	8	1	2 5	7	6	1	8	2	25	10	7 7

There were no postoperative deaths Late deaths totalled 7 (5 per cent), of these, 2 were not from tuberculosis but from coronary disease two years after operation, and from myelogenous leukemia one year postoperatively In the 5 late tuberculosis deaths, the causes were as follows progressive disease in 3 cases, death after pulmonary resection in 2 cases (operation performed elsewhere in 1 of these)

As regards present status of the 137 patients treated with surgical collapse, 130, or 95 per cent, are living Of the living 107, or 82 per cent, are well with negative sputa, 10, or 8 5 per cent, are positive or have unstable lesions, but are considered salvable, 3, or 2 per cent, are hopelessly ill, 10, or 7 7 per cent, are alive but inadequately followed up

RESULTS IN UNILATERAL RESECTION SURGERY

Seventy-nine patients had unilateral resection, as shown in Table VI Postoperative complications for the 79 resection cases totalled 9, or 11 per cent They occurred most commonly in the multiple resection group of which there were 5 Of these, 1 patient had a bronchopleural fistula and another a tuberculous wound infection Both had been war prisoners with a poor nutritional background. Two patients had postoperative hemorrhage into the pleural space which required no surgical interference One patient had an air leak which closed with complete re-expansion after a combination of phrenic crush pneumoperitoneum, and continuous suction. One patient with pneumonectomy had a wound infection with contralateral spread both of which eventually cleared completely another had poor wound healing with a final good result. One patient with lobectomy had postoperative hemorrhage into the pleural space that was absorbed without active interference. In one wedge resection, poor healing occurred without infection and with a good final result. Thus, of the 9 postoperative complications the last 7 listed cleared, leaving no disability. Late complications occurred in 4 or 5 per cent of all patients. Two patients had stump ulcers with positive sputa following lobectomy. Both cleared completely on further antibiotic therapy. One patient after segmental and another after wedge resection had late ipsilateral spread one of which has now cleared.

Table VI Results in Unilateral Surgery—Pulmonary Resection

	PNEUMONECTOMY	LOBECTOMY	LOBECTOMY PLUS OTHER RESECTION	OTHER MULTIPLE RESECTION	SEGMENTAL RESECTION	WEDGE RESECTION	LESIONECTOMY	TOTAL
NUMBER OF CASES	14	19	9	5	7	22	3	79
Sputum Conversion	13 (93%)	18 (95%)	8 (89%)	5 (100%)	6 (86%)	21 (95%)	3 (100%)	74 (94%)
Tuberculous Complications								
Postoperative	2 (15%)	1 (5%)	4 (44%)	1 (20%)	0	1 (5%)	0	9 (11%)
Late	0	2 (10%)	0	0	1 (14%)	1 (5%)	0	4 (5%)
Deaths								
Postoperative	1 (7%)	0	1 (11%)	0	0	0	0	2 (2.5%)
Late	0	0	1 (11%)	0	0	0	0	1 (1%)
Living (July, 1954)	13 (93%)	19 (100%)	7 (8%)	5 (100%)	7 (100%)	22 (100%)	3 (100%)	76 (96%)
Well with sputum negative	13 (100%)	18 (95%)	7 (100%)	5 (100%)	6 (86%)	21 (95%)	3 (100%)	73 (96%)
Salvable	0	0	0	0	1 (14%)	0	0	1 (1%)
Hopelessly ill	0	0	0	0	0	1 (5%)	0	1 (1%)
Follow up inadequate	0	1 (5%)	0	0	0	0	0	1 (1%)

Postoperative deaths occurred in 2 patients (2.5 per cent). One which followed pneumonectomy was due to cardiorespiratory failure, the other, after multiple resection was a result of the tuberculous wound infection quoted in the postoperative complications previously. Late death occurred in 1 patient and is listed under multiple resection. It was due to right-sided heart failure after a lower lobectomy done as treatment for a bronchopleural fistula arising from a previous multiple resection. Thus total deaths, including postoperative and late, were 3 or 3.8 per cent.

Summarizing, in 79 patients with unilateral pulmonary resection postoperative complications occurred in 9, or 11 per cent, late complication in 4, or 5 per cent. Nine of these 13 complications cleared with no residual disability. Death occurred in 3 cases, or 3.8 per cent, of which 2 were postoperative and 1 late. As regards present status, 76 patients (96 per cent) are living; of these 96 per cent are well with negative sputum, 1 per cent salvable, 1 per cent hopelessly ill, and 1 per cent untraced.

Of special interest is the thoracoplasty failure group comprising 21 patients of whom 1 died postoperatively and the remaining 20, or 95 per cent, are now well with negative sputum.

Bilateral Surgery.—Twenty-five patients had bilateral surgery, but it should be pointed out that in 17 of these the surgery on one side had been done before the five-year study period. The various combinations of bilateral surgery are shown in Table VII. It will be noted that the commonest procedure was thoracoplasty. It was most frequently combined with plombage which was extrapleural in 5 patients and extraperiosteal in 7. Bilateral thoracoplasty was performed in 4 patients, and bilateral resection in 3. The incidence of other combinations was as follows: extrapleural-extraperiosteal plombage, 1; thoracoplasty-extrapleural pneumothorax, 1; thoracoplasty-resection, 2; thoracoplasty-cavernostomy, 2. In 5 patients with bilateral surgery, further secondary operations were done as follows: resection, 2; cavernostomy, 2; revision, 1.

TABLE VII. BILATERAL SURGERY 1949 TO 1953—25 CASES

TYPE	BOTH SIDES DURING 1949 TO 1953	ONE SIDE BEFORE 1949 TO 1953	TOTAL	FURTHER SECONDARY OPERATIONS	
Thoracoplasty—thoracoplasty	-	4	4	Cavernostomy	1
Thoracoplasty—extrapleural pack	-	5	5	-	
Thoracoplasty—extraperiosteal pack	2	5	7	Revision Resection	1 1
Extrapleural pack—extraperiosteal pack	-	1	1	-	
Thoracoplasty—extrapleural pneumothorax	1	-	1	Resection	1
Thoracoplasty—resection	1	1	2	-	
Thoracoplasty—cavernostomy	1	1	2	Cavernostomy	1
Bilateral resection	3	-	3	-	
TOTALS	8	17	25		5

Results in Bilateral Surgery.—The results varied with the indications, but there were relatively more salvage cases in the bilateral than the unilateral group and hence over-all results were not so good. Patients in the thoracoplasty-plombage group had on the whole a good preoperative outlook for success. Ten of these 12 patients, or 83 per cent, are well with negative sputum; conversion of sputa was primary in all but one, who finally became negative after revision of the thoracoplasty. The bilateral thoracoplasty group was composed of essentially salvage cases, considered at the time unsafe for resection and found at operation not suitable technically for plomb age Only 1 of these 4 patients (25 per cent) is well with negative sputum in this case conversion took place only after cavernostomy was performed as a secondary procedure Of the other 3 one died postoperatively of cardiorespiratory failure after wax pack removal and thoracoplasty Two are alive and well but with positive sputa at times They are not respiratory cripples now but probably would be after secondary resection if they survived it

Bilateral resection was performed on 3 patients in 2 cases it was for removal of residual foci following the prolonged use of antibiotics The third was done for persistent positive gastric culture in bilateral minimal apical disease All three patients are well with negative sputa The one patient with extrapleural-extraperiosteal pack is well with negative sputum Of the 2 patients with thoracoplasty resection one was a good risk with residual foci and is well with negative sputum The other was a bad risk case with chronic disease and died ten days postoperatively of air embolism of undetermined origin. The 1 patient with thoracoplasty-extrapleural pneumothorax had borderline respiratory reserve and died postoperatively of cardiorespiratory failure following a secondary resection on the side with the thoracoplasty

The 2 patients with the combination of thoracoplasty-cavernostomy were in the salvage class and both required further secondary operations One has had a contralateral cavernostomy for a residual cavity under the thoracoplasty and is still positive presumably from a tuberculous bronchiectasis The second has recently had pneumonectomy on the thoracoplasty side and sputum so far is negative

TABLE VIII. RESULTS OF BILATERAL SURGERY 1945 TO 1953—25 CASES

	BOTH SIDES DURING 1949 TO 1953	ONE SIDE BEFORE 1949 TO 1953	TOTAL
NUMBER OF CASES	8	17	25
Sputum conversion	6 (78%)	11 (65%)	17 (68%)
Tuberculous Complications			
Postoperative	1 (11%)	0	1 (4%)
Late	0	0	0
Deaths			
Postoperative	1 (11%)	2 (13%)	3 (12%)
Late	0	0	0
Living (July 1954)	8 (89%)	14 (87%)	22 (88%)
Well and sputum negative	7 (88%)	10 (71%)	17 (77%)
Salvable	1 (12%)	3 (21%)	4 (18%)
Hopelessly ill	0	1 (8%)	1 (5%)
Inadequate follow up	0	0	0

Table VIII summarizes the results in the 25 patients with bilateral surgery In 17 of them (68 per cent) final sputum conversion took place Only 1 patient (4 per cent) had a postoperative complication namely some transitory cardiac decompensation following cavernostomy Postoperative deaths totalled 3 (12 per cent) Of the 22 living patients 17 or 77 per cent are well with negative sputum 4 or 18 per cent are salvable and one or 5 per cent is hopelessly ill

TOTAL SURGICAL RESULTS

Total results of the 219 cases analyzed are presented in Table IX. Two hundred and seven patients, or 94 per cent, are living, and 12, or 5.5 per cent, are dead. Of the deaths, 10 were associated with tuberculosis and 2 died from other causes. Of those living, 176, or 85 per cent, are well with negative sputum; 15, or 7.2 per cent, have positive sputum, or unstable roentgenograms but are considered salvable; 5, or 2.4 per cent, are hopelessly ill due to active or progressive disease, or lowered respiratory reserve, and 11, or 5.4 per cent, lack adequate data for accurate classification. The success of any treatment program in the broadest sense is based on its rehabilitation rate, in other words, how many patients are made safe to associate with others and are returned to gainful occupation. On this basis the most significant finding in the whole series is that 176 of the 210 patients, or 80 per cent, are successfully rehabilitated.

TABLE IX. TOTAL RESULTS—ALL SURGERY—219 CASES

Living (July, 1954)	207 (94.5%)
Well with sputum negative	176 (85%)
Salvable	15 (7.2%)
Hopelessly ill	5 (2.4%)
Inadequate follow-up	11 (5.4%)
Deaths	12 (5.5%)
Tuberculous	10
Nontuberculous	2
Follow-up Period	
6 months or more	196 (100%)
1 year or more	160 (81.6%)
2 years or more	117 (60%)
3 years or more	83 (42.3%)
4 years or more	47 (24%)
5 years or more	18 (9.1%)

DISCUSSION

The subject matter of this paper has been the surgical treatment of pulmonary tuberculosis in an isolated sanatorium. The self-contained surgical unit operating in an isolated area has been stressed because I believe it has become unique in these days of resection surgery or at least surgical series done under such conditions are not commonly reported. Also, the value of any surgical series, other than adding numbers to the already extensive literature, is to present any variations from average, and this applies, not only to material, but also to conditions under which the work was done. The problems of an isolated sanatorium doing its own surgery have already been mentioned in the introductory remarks. In discussing the present series, the influence of these problems on methods and results will be pointed out whenever possible.

The five-year period January, 1949, to January, 1954, brought radical changes in surgery at Manitoba Sanatorium. As elsewhere antibiotic therapy was the chief factor in the swing from collapse therapy to pulmonary resection. The lack of a resident anesthesiologist for the first years of the period affected our work in several ways. It obliged us to use local anesthesia supplemented by Pentothal sodium drip for all chest wall operations. In my opinion this is the anesthetic of choice for collapse therapy and the absence of postoperative mortality wound infection and spread of disease in the present unilateral series can be partly credited to this type of anesthesia.

O'Brien and associates in an excellent presentation of total statistics from five years of surgery point out that such statistics vary with the type of risk accepted for surgery. In their work these authors state they have attempted to extend surgical help to every patient with a reasonable chance to get well. I agree entirely with this concept but hold that even with agreement on this major premise no two series will turn out alike in composition. In each case the surgeon's personal preference plus the tools he has at hand will shape the nature of his work. Due to limited availability of intratracheal anesthesia in the earlier years of our study resection was confined mainly to thoracoplasty failures. Where others were doing increasing numbers of primary resection we were still doing thoracoplasty. No doubt some of these patients should have had primary resection and the incidence of thoracoplasty failure was unduly high. Nevertheless many were bad risk cases they withstood thoracoplasty under local anesthesia well and later most of them were successfully rehabilitated by secondary resection. With reduction of disease by prolonged antibiotic therapy and the easier availability of resection surgery we now do thoracoplasty much less often as a preparatory operation but in our opinion it still constitutes the safest approach to the surgical treatment of gross badly cavitated disease. In these cases we still like to reduce the pleural space and adjust the patient to the loss of function of this side by preliminary thoracoplasty before doing resection.

Our present belief is that there is still a place for limited surgical collapse as a definitive procedure but the indications for its use have been greatly reduced by the success of limited resection. Limited collapse is best applied by extraperiosteal plombage and our choice of packing material is paraffin rather than Lucite because it presents a more regular surface for compressing the underlying lung. In our hands the conversion rate for extraperiosteal pack is definitely lower than for limited resection. Limited resection is therefore our choice of operation except where the operative risk is formidable especially in the matter of pulmonary reserve. Poor risks tolerate extraperiosteal pack better than any other operative procedure except cavernostomy though limited resection may leave them with better pulmonary reserve if they can survive the operation. We are therefore still using extraperiosteal pack in a small number of poor risk cases.

All agree that final judgment on the relative merits of various present-day treatments must await the passage of time. It is not only a matter of choosing between operations but in some patients with residual foci time may prove that antibiotics alone will bring about cure. At present we prefer to resect residual foci if considered caseous and over 1 cm in diameter. A small group of patients not wishing surgery act as controls for future study. The best argument for resection of residual foci is the over-all relapse rate of tuberculous patients in past years Though this justifies concern, present day antibiotic therapy is already giving promise of more permanent cure Then too, the relapse rate in well-treated minimal lesions was never high, even before the use of antibiotics In 1951, I[6] reported a series of 103 patients treated for minimal tuberculosis confined to the apex of one lung These patients had received treatment predominantly with pneumothorax between 1928 and 1944, before the use of antibiotics, and showed a 91 per cent arrest of disease after 5 to 22 years' follow-up and a death rate of under 2 per cent It is perhaps true that prolonged treatment of any type gives good results in minimal disease and the most valid reason for resection in these cases is to reduce treatment time, and to improve still further an already favorable outlook In view of these indications, limited resection for minimal lesions, if justified, must have no mortality and be free of serious or permanent complications

So far, we have managed to meet these conditions in minimal cases and believe certain factors have been important in avoiding complications All patients should have at least 4 to 6 months' antibiotic treatment before surgery Positive sputum, when present, should preferably have been converted We favor wedge rather than segmental resection and follow the technique of putting tongue and groove forceps about the area to be resected, excising the wedge and then applying a continuous interlocking backstitch under the forceps before removing them Where the lesion is more deeply placed and the application of forceps involves the risk of compromising the vascular and bronchial supply to other areas, a modified segmental resection is done In this case, the bronchus to the involved area is first dissected out, cut across, and repaired The artery and the veins may also be dealt with individually Upon establishing a line of demarcation, forceps are applied about the segment, which is then excised and the cut surface repaired deep to the forceps, as in a wedge resection In this way, no raw surfaces are left and all air leaks, even alveolar ones are avoided In addition, we routinely separate all adhesions of the lung to the chest wall and diaphragm In our opinion avoiding air leak at operation and freeing the lung completely from chest wall and diaphragm are prime factors in obtaining rapid and complete re-expansion The lung is expanded as much as possible before the patient leaves the operating room and during the first postoperative day both drainage tubes can almost always be removed following complete re expansion Rapid re expansion and obliteration of the pleural space is the best safeguard against the commonly feared postoperative complications of persisting air leaks, bronchopleural fistulas, and empyema The foregoing technical considerations are, of course, not confined to the surgical management of minimal lesions, but apply to all resections As regards lung re expansion, in the larger resections, we seldom find it necessary to do partial thoracoplasty following lobectomy or in the common multiple resection combination of upper lobe, plus superior segment of lower lobe On the other hand, pneumonectomy should, in our opinion, always be combined with thoracoplasty, preferably done before the resection

Maximal return of respiratory function following resection is of great importance and is favored by rapid re-expansion We are now doing maximal breathing tests on all patients operated upon before discharge, but this was not done in the present series However the degree of return to normal function was evaluated on the basis of roentgenographic appearance, including costophrenic angle changes, diaphragmatic elevation, rib retraction, and pleural thickening Of the 71 living patients, where less than the whole lung was removed, all have complete re expansion and only 3 required apical thoracoplasty In 65, or 91 per cent, there was little or no roentgenographic evidence of diaphragmatic change, rib retraction, or pleural thickening The remaining 6 showed various degrees of diaphragmatic change, or rib retraction, *none* showed pleural thickening There are no respiratory cripples

It is commonly accepted that antibiotic therapy has not only improved the outlook in pulmonary tuberculosis, but has also changed the pathology of the disease Medlar and his colleagues[7] describe necrotic encapsulated foci after prolonged antibiotic therapy The rapid healing of endobronchial tuberculosis under antibiotic therapy with resultant narrowing, blockage, and epithelization of bronchial outlets results in so called "filled" cavities observed by all in resected lung tissue I have observed many such soft, puttylike encapsulated areas in operative specimens, especially in patients of Indian blood, after prolonged antibiotic treatment It is difficult to see how collapse would improve the healing of these areas, and the logical treatment seems resection If collapse is used, possibly the optimum time to apply it is not after prolonged antibiotic therapy, but at the beginning while bronchial drainage is still adequate and cavities if present, might heal by the preantibiotic process of collapse of their walls followed by obliteration from fibrosis Unfortunately, permanent collapse by surgical means, if applied early before much clearing of disease, must be more extensive than for residual foci and with greater sacrifice of respiratory function As regards pneumothorax, its extensive use was dropped by us, as by most others, before long-term antibiotic therapy became common, so worth-while experience with this combination is lacking One wonders if this reversible procedure induced at the beginning of treatment and protected by antibiotics might not offer far better results than formerly, and without its previous complications To those of us who made extensive use of pneumothorax during its heyday, it is interesting to speculate on its further use, but few would abandon present-day resection therapy in its favor, and it seems doubtful if it will again find a place in the armamentarium of the phthisiologist

As resection surgery continues to rehabilitate more and more chronically ill patients, the appeal for surgical aid from those remaining becomes more urgent Many of these cases are entirely unfit for *resection* In them, we have found an increasing use of cavernostomy We employ this procedure where vital capacity is too low for resection and source of positive sputum is believed limited to specific areas of cavitation. In the present series, cavernostomy was performed 7 times in 5 patients One patient had bilateral cavernostomy and another had two cavernostomies on the same side Of the 7 operations, 3 were done as primary procedures, and 4 were to drain residual cavities after thoracoplasty Four of the 5 patients are now negative In all cases, the cavernostomy wound healed completely following plastic closure, which was done on an average of seven months from the original opening of the cavity

Any appraisal of trends and results of surgery must deal with certain intangible factors Not least among them is the patient-doctor relationship which becomes unusually close in an isolated sanatorium For the doctor a thorough knowledge of the patient, born of long association, is an invaluable aid in estimating surgical risk and controlling the postoperative course Conversely, the patient develops the confidence and wholehearted acceptance of surgery, so important to a satisfactory result, by his prolonged contact with both surgical staff and other patients, who, on the whole, have had successful surgery

The doctor's problem is not so much to persuade patients to have surgery, as to dissuade the well-nigh hopeless ones from the attitude that in surgery they have nothing to lose and perhaps something to gain It is difficult to refuse surgery to such patients and more often than not surgical aid is offered them sooner or later The greatest risk, of course, is the patient with chronic, bilateral disease, and low vital capacity who is resistant to all antibiotics Technically, the surgeon is often on the horns of a dilemma, doing less than a lobectomy in the interests of conserving lung tissue may mean dissecting through diseased areas thereby courting the development of empyema and tuberculous wound infection On the other hand, removal of the whole lobe in an attempt to avoid these complications may lead to cardiorespiratory failure It is our experience, as elsewhere, that serious postoperative complications and surgical deaths come most often from this type of patient rather than from mishaps in favorable risk cases In the present series, they were most common in cases of multiple resection Fortunately, a precarious surgical venture is not infrequently crowned with success In patients where all other measures have failed, we believe surgery should not be denied if it holds any hope of success

We can probably look forward to the time when the backlog of bad risk cases has largely disappeared In the meantime, these patients continue to challenge the ingenuity of the surgeon, sometimes spoiling his surgical statistics but always stimulating his work by the occasional salvage of those cases previously considered to be hopeless

SUMMARY

Results are presented of surgical treatment of pulmonary tuberculosis at Manitoba Sanatorium in the five-year period, January, 1949, to January, 1954

Statistics are given in detail and include patients presenting a variety of indications from pure salvage to resection for residual foci in minimal disease

Altogether 219 patients received major surgical treatment of parenchymal disease and of these 80 per cent were successfully rehabilitated

The effect on treatment trends and results of doing surgery in a self-contained surgical unit in an isolated area are discussed in detail

Some observations on current treatment based on experience with the present series are submitted

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ANEURYSM FORMATION IN A HOMOLOGOUS AORTIC GRAFT IN A HUMAN[*]

Report of a Case

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Homologous aortic grafts have been used in the human since 1946[1] to replace segments of the aorta for various pathologic conditions. To our knowledge, there has been no report of the development of an aneurysm in a homologous aortic graft in man. Grindley,[2] Sewell,[3] Parsons, Gerbode, and Cox,[4] Johnson and Kirby[5] and others have reported formation of aneurysms in replaced autogenous and homologous aortic and venous grafts in the experimental animal. Grindley[2] described the occurrence of an aneurysm in an aortic homograft implanted in a dog for two years. Sewell[3] stated that aortic homografts sterilized with ethylene oxide frequently produce aneurysmal dilatation and rupture and believed this was due to destruction of the elastic tissue from the ethylene oxide treatment.

Coleman, Deterling and Parshley,[6] Kanar and associates,[7] McCune and Blades,[8] Sewell,[3] Hufnagel,[9] Hufnagel and Eastcott,[10] Shumacker and King,[11] Gross,[1] Swan,[12] DeBakey and associates[13] and others have described the fate of homologous grafts of the aorta. There is usually a marked thinning of the graft wall, loss of cellular elements, disruption of the elastic framework, and mild to marked calcific deposits. Arterial homografts do not show persistence *of their cellular elements, but serve as the scaffolding for the ingrowth* of connective tissue from the host to provide a conduit for arterial blood. The endothelium covering the intimal surface is thought to be derived from the fibroblasts and possibly endothelium of the adjacent host aorta. The blood is supplied from the surrounding tissues.

CASE REPORT

A 60 year old white woman was admitted to the George Washington University Hospital on Jan. 11, 1954, complaining of upper abdominal and flank pain on the left, of one year's duration. This pain was dull in nature but made worse by exertion. It persisted and became much more severe five weeks before admission, requiring opiates for relief. At that time, she observed swelling and tenderness along the left costal margin. The patient gave a history of indigestion of two years' duration, relieved by sodium bicarbonate. A 17 pound weight loss was noted during this time. She had had a hysterectomy twelve years previously and a known hypertension, with systolic pressures of 220 mm. of mercury, for years. *She was referred to us because of accentuation of her symptoms and evidence of* a pulsating mass in the abdomen.

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On physical examination, the patient was a well developed and fairly well nourished 60 year old woman, who appeared chronically ill but in no distress. Her pulse was 84, blood pressure 170/110 mm. of mercury and temperature 37° C. There was Grade II spasm of the arterioles on examination of the fundi. The heart was not enlarged and no murmurs were heard. A well healed lower midline abdominal scar was noted. Deep palpation of the abdomen elicited pain in the left upper quadrant, left mid abdomen, and left flank. There was no paresthesia but hyperesthesia was noted over the area of tenderness. A pulsating elongated mass, about 4 cm. in width, was felt in the region of the aorta, which could be followed from the sacrum to beneath the xiphoid.

The laboratory reported hemoglobin 14.4 Gm. per 100 c.c., hematocrit 47 per cent, leukocyte count 10,000 with 64 per cent seqmented neutrophils, 32 per cent lymphocytes and 4 per cent monocytes. The erythrocyte sedimentation rate (Wintrobe) was 16 mm. after one hour. The Kahn and cardiolipin (V.D.R.L.) tests for syphilis were negative. The urine was yellow with a specific gravity of 1.029 and an acid reaction with no albumin or sugar. There were 1 to 3 leukocytes per high power field. Serum nonprotein nitrogen was 25 mg. per cent and the van den Bergh test was negative.

There was questionable left ventricular hypertrophy on the electrocardiogram.

Roentgenographic studies of the chest proved the heart shadows normal, the lung fields clear, and an aneurysmal dilatation of the descending thoracic arota. To a lesser degree, there was dilatation of the abdominal aorta. There was considerable calcification of the ascending arch and abdominal aorta, but the dilated portion of the descending aorta was not outlined with calcium. The vertebrae were not eroded. On angiocardiograms made by Doctor A. D. Kistin, a fusiform dilatation of the descending thoracic aorta was seen, with a thick wall extending from the sixth thoracic vertebra to the diaphragm (Fig. 1). The abdominal aorta appeared tortuous and somewhat wider than normal with no localized aneurysmal formation.

On Jan. 20, 1954, under Pentothal sodium and ether anesthesia induction, tracheal intubation was carried out. The anesthesia was maintained with nitrous oxide, oxygen, and ether. A thoracodorsal incision was made and the eighth rib removed subperiosteally. The pleural cavity was opened and the lung collapsed. The aorta was tortuous and enlarged in its course from just below the arch to the diaphragm. Approximately 7 cm. below the subclavian artery the aorta ballooned and for a length of 5 cm. was twice the size of the normal appearing vessel. From this point it increased to about three times the normal size for 10 cm. where it abruptly narrowed and made an acute angle with the distal aorta. In the wall of the aorta numerous calcified plaques were palpable. There were several 0.5 to 1 cm. dimples in the wall which appeared *thinner* and pulsated vigorously.

The mediastinal pleura was incised. The aorta was mobilized from the diaphragm to approximately 5 cm. below the arch, with individual ligation of all intercostal and esophageal vessels. At this point, the tortuosity was much more evident and the ballooning of the small dimples was more pronounced.

Because of the preoperative suspicion of an abdominal aneurysm, the diaphragm was opened. On palpation, the abdominal aorta was slightly tortuous and dilated but without evidence of aneurysm formation. The diaphragm was closed with interrupted silk sutures. The sixth and seventh ribs were cut posterior to their angles for wider exposure. A freeze-dried aortic graft untreated with ethylene oxide, obtained from The Walter Reed Army Medical Center, was reconstituted. All its small branches were doubly ligated with 4-0 silk by another team. A Potts' clamp was applied proximally and distally to the aneurysm and the aneurysm excised. It measured 17 cm. in length. The proximal aorta contained several yellowish plaques in its intima which were dissected free. The graft was anastomosed to the aorta using two lateral stay sutures of 4-0 silk, and also, running posterior and anterior sutures of the same material. The aorta was clamped for forty minutes. The blood pressure prior to aortic occlusion was 160/100. After occlusion it rose promptly to 240/100. A phlebotomy of 750 c.c. was performed and Pendiomide (22 mg.) was administered for its hypotensive effect The blood pressure fell to 120/80 For four minutes after the clamps were released, there was no blood pressure obtainable The blood withdrawn by phlebotomy was rapidly reinfused and within fifteen minutes the blood pressure was 100/60

The graft assumed an inverted U position which made its distal end kink just above the line of anastomosis Because of the kink, it was necessary to resect a portion of the graft Once again the distal and proximal host aorta was cross clamped and a 4 cm segment of aortic graft, directly in the center of the graft, was removed The graft was reanastomosed The time of the second occlusion was twenty minutes

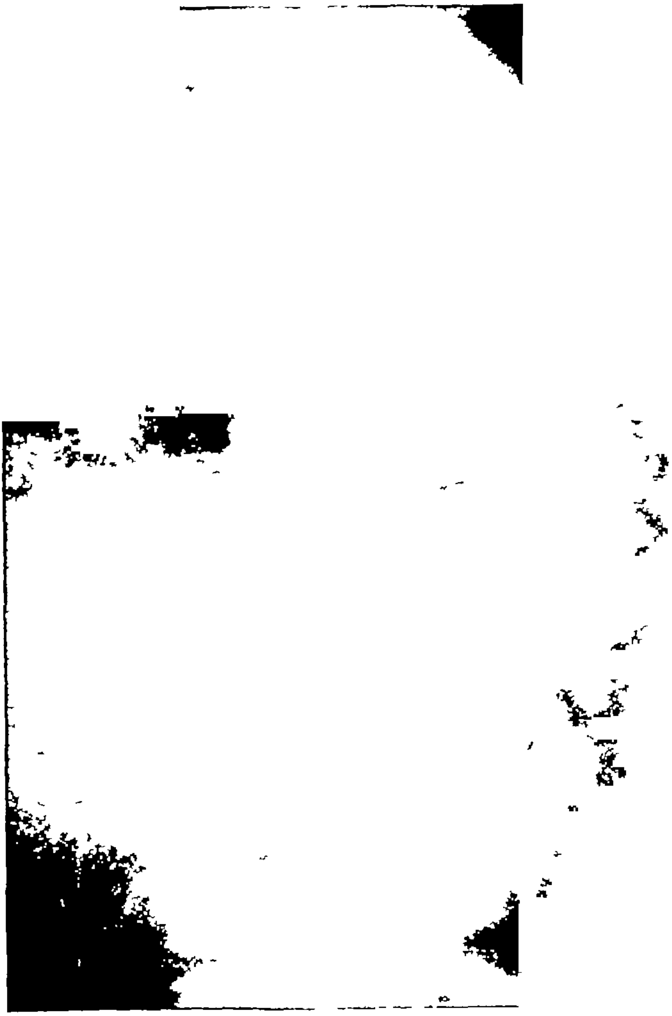

Fig 1—Original aneurysm as seen on an angiocardiogram

The graft lay nicely in the bed with no tortuosity or kink, and hemostasis was easily controlled with several interrupted silk sutures

The blood pressure rose to 160/90 following the second cross clamping of the aorta and fell to 90/0 after the clamps were released It soon rose to 120/80 and remained at that level throughout the completion of the operation

It was impossible to close the mediastinal pleura. The thoracotomy incision was closed, leaving an intercostal catheter for water seal drainage.

The patient tolerated the procedure well and was returned to her room in good condition with palpable dorsalis pedis pulsations.

Grossly, the host specimen consisted of a segment of aorta measuring 12.5 cm. in length and averaging 4 cm. in width. At one end there was a 1 to 2 cm. saccular aneurysmal dilatation. The intima was markedly thickened and contained yellowish white atheromas with areas of calcification.

A second specimen consisted of an 8 mm. segment of aorta measuring 1.8 cm. in diameter, labeled "Segment of homologous aorta."

On microscopic examination of the host aorta, there was profound intimal thickening and proliferation with many cholesterol clefts and mononuclear macrophages containing hemosiderin. Focal areas of basophilic stippling marked the sites of calcification. The media was thinned beneath the atheromatous plaques, but showed no evidence of mucoid degeneration. The adventitia was the site of recent hemorrhage (operative), but otherwise showed no abnormalities. The vasa vasora and vena vasora were normal in appearance.

Microscopically, the intima of the segment of homologous graft was not thickened. The media was normal in appearance. There were no breaks in the elastica and no "palisading" of nuclei was seen. Very little adventitia was seen in the portion of transplant submitted for study (Fig. 2, *A*).

Immediately after returning to the ward, the patient's blood pressure rose to 160/110. Six hours later it fell to 90/70 and remained so for six hours. It then rose to 200/110 and varied in this region throughout the hospital stay.

In the first twenty four hours the urinary output was 300 c.c. and the nonprotein nitrogen was 47 mg. per cent. The second postoperative day the urinary output was 1,100 c.c. and the nonprotein nitrogen was 43 mg. per cent. The third postoperative day diuresis to 2,200 c.c. occurred and the nonprotein nitrogen was 62 mg. per cent. On the fourth postoperative day the nonprotein nitrogen was 35 mg. per cent, serum potassium 4.8 mg. per liter, serum sodium 151 meq. per liter. The patient continued to improve and was discharged on the twelfth postoperative day, her only complaint being some vague left upper abdominal pain. The blood pressure was 180/120 and the peripheral pulsations of all vessels were satisfactory.

Comment.—The aorta was clamped for a period of forty minutes for the original anastomosis and again for twenty minutes in order to remove a segment of the graft because of kinking and partial obstruction of the blood flow. This possibly accounts for the transient oliguria and retention of the nitrogenous products. Studies for hepatic damage and blood incompatibility were negative.

Hepatic and renal injuries are not noted in resections of coarctations with primary anastomosis or replacement by a homograft because of the tremendous collateral circulation.[14] On the contrary, in aneurysmal disease there may be serious complications because of the lack of the development of adequate collateral circulation and because of thrombosis of the intercostal vessels found in arteriosclerotic diseases with aneurysms.[15] DeBakey, Cooley, and Creech[16] stated that the closer the aorta is cross clamped to the arch, the more likelihood of spinal cord injury. This would seem true, also, for the liver and kidneys if the aorta is clamped above their blood supply. If, however, the occlusion is below the renal vessel, there is usually no damage to vital organs.

Toleration of occlusion of the aorta appears to vary greatly in different individuals. Lam and Aaron[17] cross clamped the aorta for twenty five minutes and again for fifteen minutes and noted a transient cord damage in a resection of an aneurysm of the thoracic aorta. DeBakey[14] has occluded the thoracic aorta for forty five minutes and Brock and Graham[18] for eighty minutes with no cord or renal damage. Beattie and co workers[19] and Lam and Aaron[17] have also demonstrated that the time required to produce cord damage by aortic occlusion in the experimental animal is quite variable.

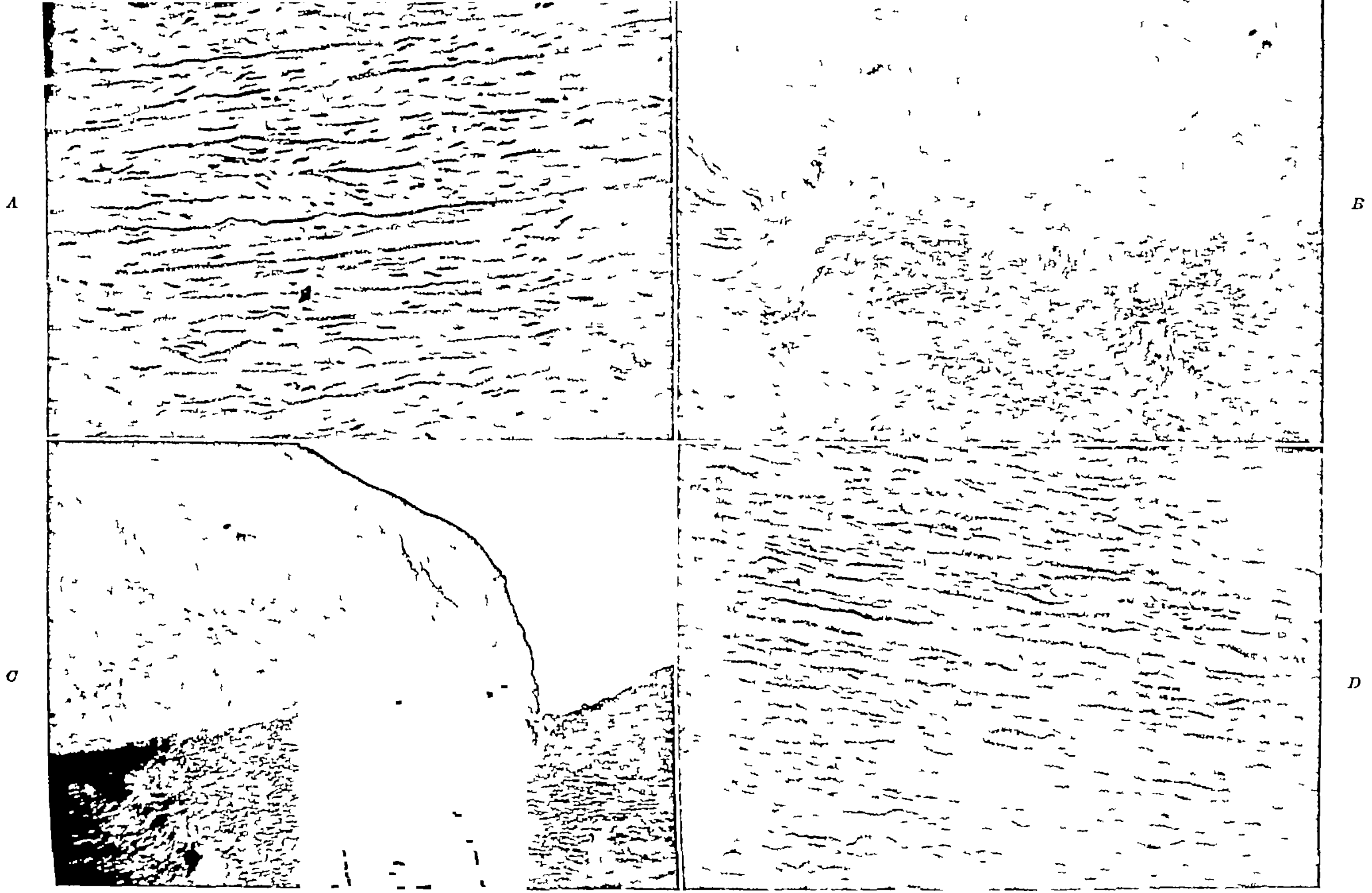

Fig 2 —*A* Section of the original freeze-dried homologous aortic graft showing the media and nuclei to be normal in appearance *B* Section of aortic graft and host aorta one year after transplant, showing the line of demarcation between the graft and the patient's aorta and an atheromatous plaque above it. *C*, Section of aortic graft and host aorta, showing the atheromatous plaque as it extended over the graft from the host aorta. *D* Section of the aortic graft one year after transplanting No [illegible]

Second Admission.—On May 20, 1954, the patient was readmitted to the George Washington University Hospital with a four week history of intermittent rash of the lower extremities, malaise, anorexia, chills, sweats, and fever. There was arthralgia of a migratory nature and redness and heat in the affected joints. Two weeks prior to this admission she was hospitalized in her home town for six days. There a leukocytosis of 25,000 was noted, which rose and fell with intermittent fever. She had a recurrence of pain in the left flank and chest, reminiscent of the pain prior to removal of the aneurysm in January 1954. On physical examination, the blood pressure was 180/105 in the right arm, pulse 100, respirations 18, and rectal temperature 39° C. She appeared chronically ill and there was evidence of weight loss. Hepatosplenomegaly was noted. All pulses in the feet were present bilaterally. There were no nodes palpable. The heart sounds were normal. The radiologist reported "questionable bulge in the region of the operative site."

The white blood count varied from 8,000 to 10,200, with a normal differential except for elevated eosinophils from 8 to 10. The hemoglobin was 11.8 Gm. and the erythrocyte sedimentation rate was 27 mm. (Wintrobe) after one hour. The urine remained negative and concentrated to 1.014. A bromsulfalein liver function test of 25 per cent retention was reported and substantiated. Serum bilirubin was 0 mg. per cent direct and 0.3 mg. per cent indirect. The total serum protein was 6.48 Gm. per cent with albumin 3.65 Gm. per cent and globulin 2.83 Gm. per cent. The thymol turbidity was 5 units and a cephalin flocculation was reported as 1 plus in 24 hours. The Kunkel globulin was 11 units. The sternal marrow biopsy was "compatible with infection but otherwise normal." Culture of the marrow, repeated blood cultures, and a femoral artery culture remained sterile. Proteus and *Escherichia coli* were recovered from a urine culture. Multiple agglutinations were negative. No blood, ova, or parasites were seen in 3 stool specimens. The blood urea nitrogen was 13 mg. per cent.

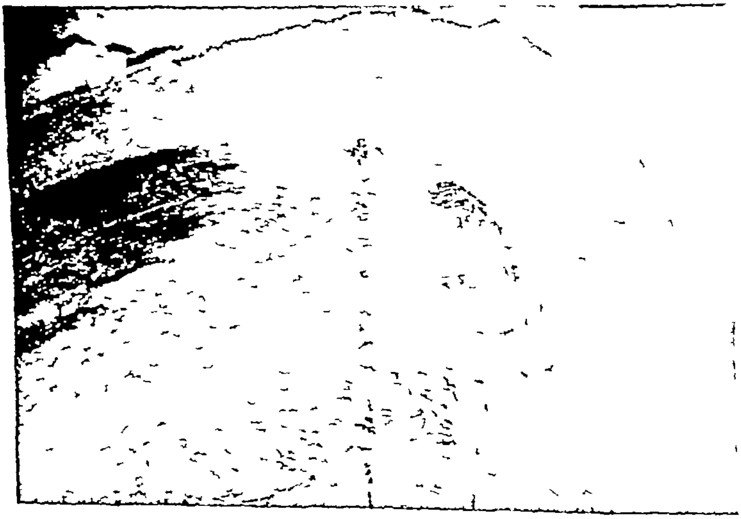

Fig. 2E.—Section of the graft aneurysm showing absorption of the media and atheromatous plaque formation and suture granulomas in middle of section.

Even on large doses of salicylates the fever persisted. In spite of negative venous and arterial cultures, the diagnosis of endarteritis at the graft site seemed tenable. Massive doses of penicillin were instituted, as in the treatment of endocarditis, with a prompt subsidence of temperature and a return of well being. She was discharged and was to continue to take penicillin at home for another three weeks.

The diagnoses at discharge on June 5, 1954, were endarteritis at graft site, hepatitis, and hypertension The cause of the hepatitis remained obscure

Comment—In retrospect, the aneurysm in the graft was present at this admission, evidenced by a return of her preoperative pain and the x ray appearance of the chest

Lower extremity petechiae, migratory arthralgia, chills, sweats, malaise, and anorexia promptly subsided with the institution of penicillin therapy, making a diagnosis of endarteritis at the graft site reasonable, in spite of negative cultures

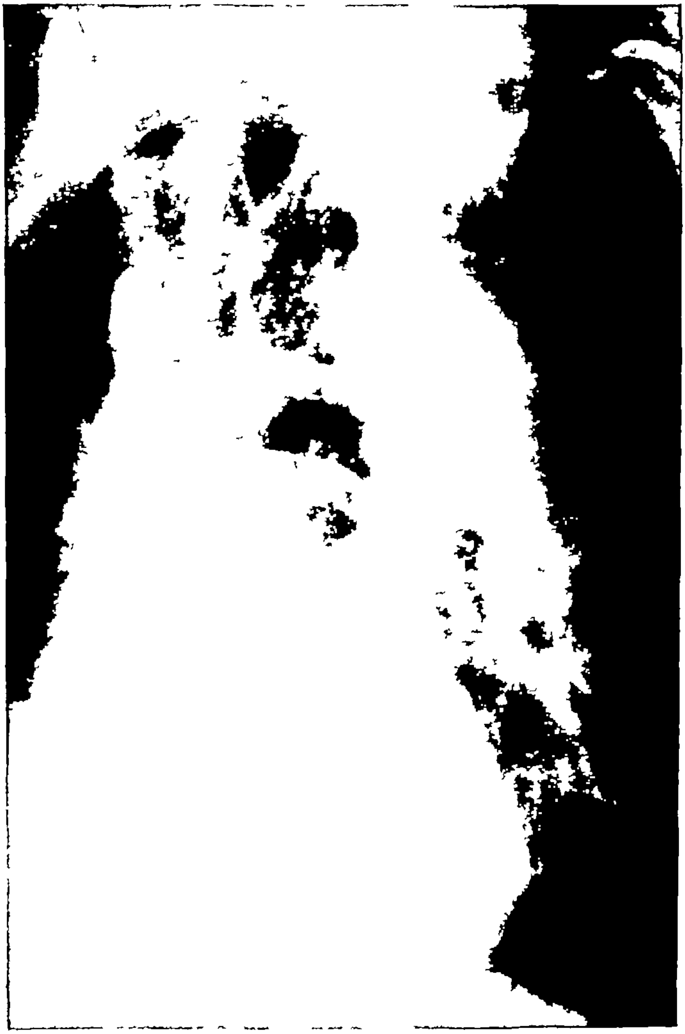

Fig 3—Anterior oblique film showing the kink and aneurysm in the graft one year after transplant as seen on an angiocardiogram

The etiology of the hepatitis remains obscure Hepatic damage could have occurred from aortic occlusion at the time of surgery, from blood transfusions, or as a response to the endarteritis

Interval History—During the summer of 1954, she gained strength and vigor, but noted intermittent pain in the left flank and chest, particularly when her blood pressure rose Liver function tests returned to normal, but there was evidence of a considerable difference in the blood pressure in either arm, the right being higher than the left. Serpasil in large doses did not affect the hypertension. She was taught to take her blood pressure at home in preparation for administration of ganglionic blocking agents.

Because of the great discrepancy in the blood pressure in the two arms, and because of a steady rise in her hypertension, she was hospitalized again in early December, 1954, with the suspicion of another aneurysm in the arch. The intermittent pain had become constant.

Under the fluoroscope, a pulsating mass was seen in the graft site, but no other aneurysm was noted. Sodium Amytal sedation lowered the 240/130 pressure in the right arm to 130/80. Renal and hepatic function were excellent at that time. The patient was discharged before starting ganglionic block with drugs because she desired to attend to some personal affairs. However, an acute exacerbation of her symptoms required readmission to the hospital in a few days.

Final Admission.—On this admission, the patient appeared quite apprehensive and in acute distress. She was unable to lie on her left side. The pulse was 82 and regular. Blood pressure in the right arm was 225/110 and 160/100 in the left arm. In the right leg, the pressure was 180 systolic, the diastolic pressure was not obtained. There was no change in the eyegrounds. Moist râles were heard posteriorly in both lower lung fields and acute tenderness was elicited in the left midquadrant of the abdomen and left flank. The widened abdominal aorta was again palpated with strong pulsations. The pulsations of the vessels of the lower extremities were decreased but present.

The laboratory findings were hemoglobin 14.8 Gm., hematocrit 50 per cent, and leukocytes 8,250 with 61 segmented neutrophils and 34 monocytes. The blood urea nitrogen was 19 mg. per cent. The urine was yellow and acid in reaction with a specific gravity of 1.011. Other urine studies were negative.

On roentgenographic, fluoroscopic, and angiocardiographic studies, sharp angulation at the lower part of the descending thoracic aorta was noted, with a prominent rounded bulge at this site (Fig. 3).

On Jan. 3, 1955, a right thoracoabdominal incision was made through the old scar. The lung was closely adherent to the bulging graft. The aorta was freed proximally and distally and encircled with umbilical tapes. The lung was dissected from the graft. A considerable amount of oozing was encountered. The graft had again formed an S shaped tube with the aorta and a localized aneurysmal dilatation was noted at the anastomotic site, which was 4 cm. in width and pulsated against the eighth, ninth, and tenth ribs (Fig. 4). It is important to record that the original aortic graft was not treated with ethylene oxide.

The entire graft and aneurysm were freed from the surrounding tissues from the celiac axis to 2 cm. below the subclavian artery. Intrathoracic hypothermia[20] was established allowing the temperature to fall to 31° C. to aid in preventing damage to the vital structures. The fifth rib was resected and the pleura divided for more adequate exposure.

The length of graft required was measured and a Vinyon N tube* the size of the aorta was cut to that measurement, allowing an overlap of 2 cm. to be folded upon itself at each end. The aorta was occluded proximally and distally. The graft and adjacent aorta, 2 cm. on each end, were excised. The Vinyon N graft was then anastomosed using two lateral stay sutures of 4-0 silk, and running posterior and anterior sutures of the same material. The clamps were released with slight bleeding from a needle hole at the distal anastomosis, which promptly ceased (Fig. 5). The aorta was cross clamped for thirty three minutes.

The blood pressure at the beginning of the operation was 160/100 and 110/80 prior to occlusion of the aorta. It promptly rose to 220/100 and remained stable until the clamps were released, at which time it fell to 110/60 and did not deviate throughout the

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*The authors express their appreciation to Drs. William Sewell and Robert Koth of the Naval Medical Research Institute, National Naval Medical Center, Bethesda, Maryland, for supplying the Vinyon N graft and technical advice in its use.

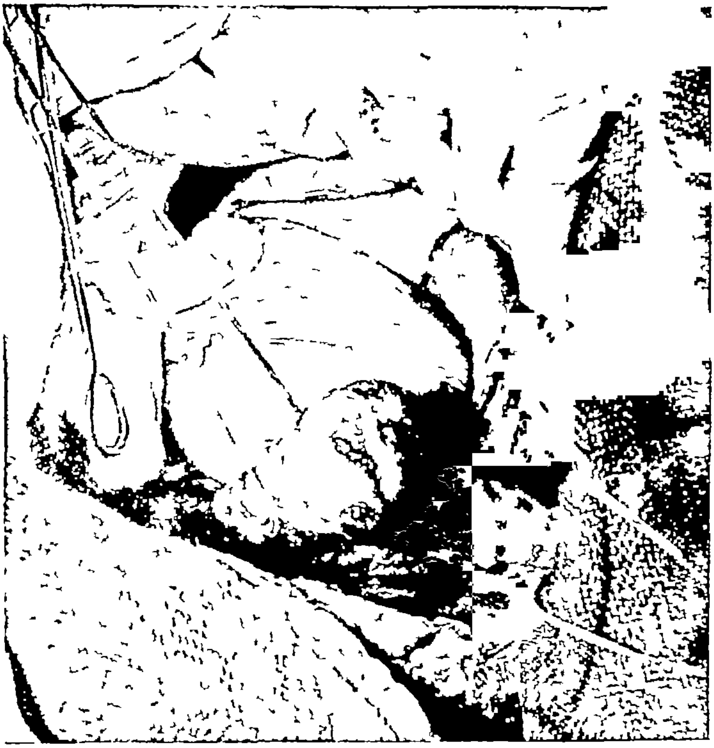

Fig 4 —Graft in the thoracic aorta with kink and aneurysm formation

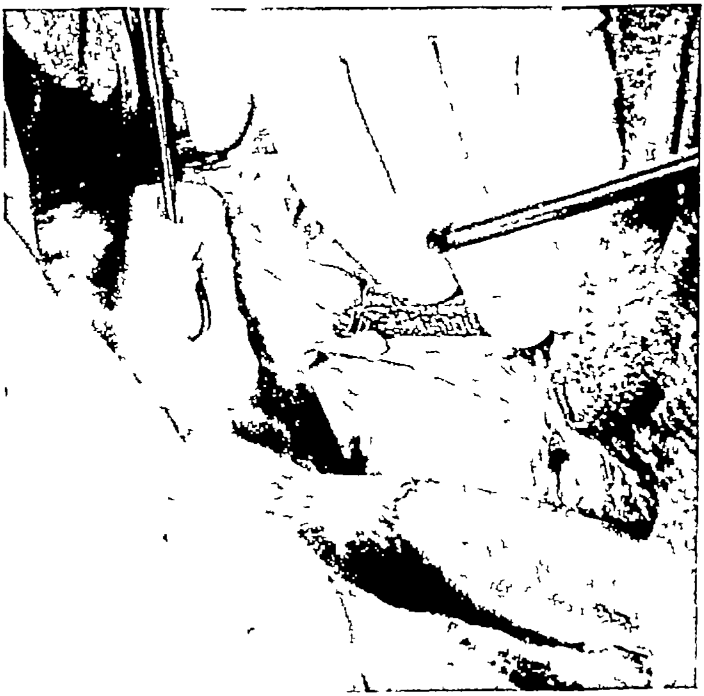

Fig 5 —Vinyon N tube replacement in descending thoracic aorta

completion of the procedure. The diaphragm and chest wall were closed. A water seal drain was placed in the pleura. Blood totaling 2,300 c.c. was given intravenously. The patient's condition was satisfactory throughout the procedure. All peripheral pulses were easily palpated and of good quality at the completion of the operation.

Grossly, the specimen consisted of a segment of aorta measuring 14 cm. in length with an average diameter of 3.2 cm. in its unopened state. There were three suture lines. The middle anastomosis was 8 cm. from the proximal end and was intimately associated with a saccular aneurysmal dilatation or evagination measuring approximately 3.0 cm. The proximal line of anastomosis was located 3 cm. from the proximal end of the specimen. There was marked atherosclerosis of the patient's own aorta evidenced by grayish white to yellow plaques, and at two points these plaques extended on the proximal portion of the graft for a distance of 0.5 cm. They could be peeled off the underlying graft which was still smooth and grayish white. There were two small yellowish plaques in the graft proper and these were found at the middle suture line at the stoma of the aneurysmal sac. The larger of the two measured 0.3 cm.

At the distal suture line, which was 2 cm. from the lower end of the specimen, an abrupt change from the smooth graft surface to the patient's own sclerotic aorta was again noted. The degree of sclerosis here was equivalent to that found at the proximal end. Several plaques extended on the distal end of the graft and these again could easily be peeled off. The intimal surface of the aneurysm was somewhat more wrinkled and thicker than the rest of the graft.

Seen in microscopic sections from the proximal end of the patient's own aorta was marked atherosclerosis evidenced by intimal thickening and sclerosis. There was infiltration by fibroblasts. There were plaques under which the media was thinned, but intact. Suture granulomas were seen with a foreign body tuberculoid reaction. Obliterative endarteritis and focal perivascular accumulations of lymphocytes and mononuclear macrophages were also noted. The line of demarcation between the graft and the patient's own aorta was striking (Fig. 2, *B*). There was no thickening of the intima of the graft. The continuation of the intimal plaque from the patient's vessel to the surface of the graft was easily seen (Fig. 2, *C*). The media of the graft was relatively acellular except in one area close to the proximal suture line where a flame-shaped scar extended inward from the adventitia (Figs. 2, *B*, and *C*). Beyond this area, the media was almost devoid of nuclei (Fig. 2, *D*). The adventitia was widened, markedly sclerotic, and there was recent hemorrhage (operative) in the periadventitial fibro fatty tissue.

TABLE I. LABORATORY WORK

POSTOPERATIVE DAY	URINARY OUTPUT	HEMATOCRIT PER CENT	BLOOD UREA NITROGEN MGS. PER CENT	Na MEQ. PER CENT	K MEQ. PER CENT	Cl MEQ. PER CENT	CO₂ MEQ. PER CENT
1	350 c.c.	43					
2	360 c.c.	35	54	129	5.2	94.0	17
3	2,700 c.c.	28	65	136	5.0	92.0	23
4	3,400 c.c.	33	75	134	3.6	93.7	18
5	3,500 c.c.		60	144	4.0	95.0	21
6	3,175 c.c.	41	37			96.4	20
7	2,320 c.c.	42	36	144	3.9	95.3	
10	2,000 c.c.	39	28	135	3.6	107.0	20

The only areas of intimal plaque formation in the graft proper, together with focal areas of almost complete absorption of the media, were seen in sections from the middle suture line and aneurysm stoma (Fig. 2, *E*). In these areas, the thickened intima was almost in opposition to a widened sclerotic adventitia. The intimal plaques in this area were frequently but not always related to suture. The greatest degree of intimal thickening was noted at the outpouching of the sac.

The distal anastomosis was similar to the proximal suture line and the marked atherosclerosis of the patient's own aorta was noted again

Most of the graft segment showed almost no visible nuclei in the media, with two exceptions—one close to the area of the proximal anastomosis where the flame shaped scar was noted and the other in the vicinity of the middle suture line This loss of nuclei was most strikingly seen by comparing the section of the transplant taken just prior to the initial placement of the graft with the resected specimen from the second procedure (Figs 2, *A* and *D*)

Soon after the operation the patient developed a sinus tachycardia to 140 beats per minute, and the blood pressure rose to 156/90 She was awake and oriented The electrocardiogram confirmed the sinus tachycardia and was otherwise normal It remained so throughout her hospital stay At the end of the first twenty four hours, the urinary output was 350 c c This urine concentrated to 1 014 and there were many red cells, hyaline and granular casts seen in the noncentrifuged specimen (Table I) The second postoperative day the patient voided only 75 c c in sixteen hours Fluids were limited to a total of 1 L, which consisted of 750 c c of a mixture of physiological sodium chloride and ⅙ molar lactate to provide an excess of sodium The hematocrit had fallen and 250 c c. of whole blood followed this mixture intravenously Diuresis began on the third postoperative day and liquids by mouth were started Following that, the patient was given electrolytic solutions and blood as indicated by the daily laboratory findings (Table I) Oral feedings were given as tolerated, in spite of which she continued to have a mild acidosis and mild hypochloremia This was treated with potassium chloride orally

Nausea and some vomiting were a problem during the postoperative course and were attributed to a known intolerance to narcotics which averaged only 2 to 3 hypodermics per day

At the time of discharge the patient was free of pain and complained only of soreness from the incision

COMMENT

There were several factors contributing to the aneurysm formation in the graft There probably was a persistent kink in the graft unrecognized at the time of the first procedure, although it was believed that defect had been corrected Hypertension increased the force of the jet which bombarded the graft already weakened by the endarteritis noted on her second hospital admission

It is interesting that the calcific deposits were found only at the anastomotic sites, the graft being singularly free of atheroma or calcium deposits except at suture lines

McCune and Blades[8] have demonstrated aneurysm formation in grafts of dogs' aortas where kinking occurred Infection has long been an etiological factor in aneurysms

CONCLUSION

The recognition and removal of an aneurysm which occurred in a homologous aortic graft are reported Possible factors in the occurrence of the aneurysm are noted

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ALVEOLAR-CELL CARCINOMA OF THE LUNG (PULMONARY ADENOMATOSIS)

A STUDY OF 155 CASES, 10 REPORTED FOR THE FIRST TIME

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ALVEOLAR-CELL carcinoma of the lung or pulmonary adenomatosis is a primary malignant tumor which is increasingly recognized and reported as time goes on. There has been some confusion in nomenclature, some difference of opinion as to cell origin, considerable difficulty in reaching a diagnosis ante mortem, and substantial failure to treat the patient with the affliction successfully. While some observers have come to believe that alveolar cell carcinoma is a late stage of pulmonary adenomatosis when metastases may have developed, it is certain that they are the same tumor. Alveolar cell carcinoma is the preferable designation. The nomenclature applied to this disease variously has been papillary gelatinous adenocarcinoma, primary alveolar-cell tumor, pulmonary adenomatosis, muco cell papillary adenocarcinoma, diffuse epithelial hyperplasia, diffuse primary alveolar epithelial carcinoma, malignant adenoma, cystic papillary lung tumor, muco epithelial hyperplasia, carcinomatoides alveologenic multicentric.

The earliest records of the tumor are by Malassez in 1876 and Musser in 1903. Since then desultory reports have been published, which have become more numerous in the last fifteen years. Even so, I have been able to find only 145 proved case reports to which are now added 10 that have come under my personal care or observation. It is very likely that many cases have escaped recognition because of the difficulty of diagnosis. Clagett found 7 cases in 275 lung resections. Ikeda found 8 in 206 proved cases of carcinoma of the lung. Adler reported 20 in 374 primary malignant growths of the lung. Paul believes that 20 per cent of all pulmonary malignancies are composed of alveolar carcinomas.

The etiology of the tumor is not established. Undoubtedly it develops as a response to a single or many factors, and to certain nonspecific irritants as is true of cancer in general. The most intriguing idea is that of causation by a virus or by peculiar ultramicroscopic bacteria, because of its morphological resemblance to epidemic zaagsiekte of sheep. This disease was the subject of a thorough study and report made by the African Expedition of the Rockefeller Institute for Medical Research. They found that the zaagsiekte (sometimes spelled jagziekte) is a specific catarrhal pneumonia in sheep peculiar to South Africa. Initial symptoms are noticeable when sheep are driven for long distances, hence the designation "drive sickness." The pneumonia begins with engorgement of the capillaries. It is followed by accumulation of macrophages

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and lymphocytes with many mucous plugs passing into the alveolar lumina There is definite thickening several millimeters in diameter in localized areas of interalveolar tissue Then epithelial papillary proliferation develops in the alveoli. It seldom gives rise to metastasis even to adjacent lymph glands, probably because death occurs before metastases have a chance to develop Primary infiltration of interalveolar tissue continues and may lead to fibrosis and consolidation or leukocytes may accumulate in large numbers, penetrate into the alveoli and form areas of acute pneumonia There are many stages of reaction in one and the same lung The prevailing view that the zaagsiekte is due to a specific virus and is directly contagious is in all likelihood correct in spite of the failure to transplant the disease by direct inoculation or by inhalation of diseased tissue Thus, while zaagsiekte may be due to a single and specific virus the pathological complex on the whole is such as might be caused by a variety of predisposing and exciting factors over a considerable period of time Perhaps in the naturally occurring disease interalveolar thickening is such a factor In the search for microorganisms, no nematodes nor parasites (for example malarial organisms) were found Several kinds of bacteria were present but never in proliferating epithelium as is true of most hyperplasias and tumors The adenomatous condition present is merely a kind of epiphenomenon Very likely the pulmonary alveolar epithelium of sheep is peculiarly unstable, and is unusually susceptible to growth stimuli or to influences tending to invalidate normal inhibitory mechanisms Epithelial proliferatoin, though supplementary, contributes to the death of the animal by diminution of respiratory area, and a lessening of their vitality, thus rendering the sheep more susceptible to bacterial action

In the human being hyperplasia and metaplasia in the pulmonary alveoli can be produced by various stimuli They are observed in

1 Bacterial and viral (a) pneumonitis (b) empyema, (c) pleurisy including old pleuritic adhesions (d) chronic granuloma for example, syphilis and tuberculosis and (e) lung abscess and gangrene

2 Nonbacterial pneumonitis (a) lipoid, (b) chemical and (c) aspiration

3 Vascular disturbance which produces chronic anoxia as in an old mitral and aortic valvular disease which develops chronic passive congestion, infarcts atelectasis, and fibrosis

4 Irritation from (a) hydrocarbons, (b) war gases, especially phosgenes, (c) silicosis, and (d) tobacco smoke

5 Physical agents (a) x-ray and (b) radium.

In a review of cancer of the lung occurring in radium ore miners of Jackymov in a two-year period made by Pirchan and Sikl, and in a similar review of the miners at Schneeborg in Saxony made by Schmorl, no alveolar-cell carcinoma was found in 9 miners who died of cancer of the lung Anthracosis and pneumoconiosis apparently were not factors

Biologic Studies in Primary Adenomatosis—Attempts to culture a virus in laboratory animals have been fruitless in the experience of a number of investigators

1 Dr Jonas Salk conducted a number of virus studies with sputum from one of my patients with proved alveolar-cell carcinoma, using monkeys and guinea pigs in his laboratory at the University of Pittsburgh He failed to find any evidence of a virus at work

2 Clagett ground up tumor and injected the emulsion into sheep, rhesus monkeys, into 2 dogs, and the internal chamber of the eyes of 5 guinea pigs There was no growth in four months He did not rule out the possibility of a virus at work.

3 Dungal reported one case of experimental transmission by extrapulmonary injection of tissue suspension

4 Grumbach produced diffuse epithelization in the lung after injection of the gall bladder with diptheroid bacilli obtained from a lymph gland of a patient with Hodgkin's disease

5 Grady and Steward, by subcutaneous injection of 1, 2, 5, 6—dibenzanthracene in mice, produced malignant tumors of alveolar origin not associated with inflammatory reaction These tumors were little different from those appearing in human beings, and were multicentric with predilection for peripheral zones of the lung Cells were observed scattered in small foci close to the pleura preceding the development of tumor nodules, and also closely adjacent to peripheral zones for expanding tumors, and were indistinguishable from alveolar phagocytes In the early stages, there was no active proliferation of these cells, only progressive swelling and enlargement In the later stages, mitotic division occurred in cells adjacent to the tumor, and in the tumor cells themselves In the latest stages, there was complete investment of alveolar walls by a layer of cuboidal cells which morphologically appeared epithelial They concluded, therefore, that alveolar lining cells, whatever their embryological origin, might be capable of differentiating into cells indistinguishable from an alveolar phagocyte, and later into an alveolar tumor cell.

6 Norris injected fluid aspirated from a patient with lobar pneumonia into a guinea pig One lung developed a zaagsiekte-like lesion

7 Sims inoculated animals with a 10 per cent suspension of tumor tissue mass, 1 monkey, 6 c c intranasally, 2 rabbits, 3 c c intrapulmonically, 1 guinea pig, intrapulmonically, 2 guinea pigs by 25 c c of atomized spray for a six-hour period in a closed chamber In none of these animals was there evidence of tumor transmission

Pathology—Alveolar cell carcinoma does not resemble any other growth It appears grossly in two forms (1) nodular, multiple growths distributed throughout one or both lungs, and (2) a diffuse form suggestive of coalescence of the nodules Both forms may occur at the same time The nodules are miliary to marble size, yellowish-gray, whitish or pink in color, globular, firm, and with fairly sharp borders The diffuse form resembles a pneumonia in a stage of gray hepatization involving a lobe or even an entire lung Even so, the appearance suggests an enlargement from multiple foci Intervening tissue may exhibit varying digrees of inflammation and necrosis There may be unilateral or bilateral pleuritis with fibrinous or serous exudate and adhesions of varying density Cavities and bronchiectasis are rare There is no involvement of bronchi or bronchioles with tumor The lungs are increased in weight In general, the changes in the lungs were more extensive than physical signs or x-ray appearance indicated.

Metastases are not a prominent or early feature They occurred in about 45 per cent of the cases, in 53 of 117 autopsies Apparently, the incidence and extent of metastases are proportionate to the duration of the disease, being less in acute cases of short duration Metastases extend by the lymphatics or blood stream in order of frequency into tracheobronchial (hilar) lymph nodes, the pleura, distant lymph nodes, pericardium, liver, kidneys, adrenals, brain, and skeletal system In Table I are recorded findings in 117 autopsies

TABLE I FINDINGS IN 117 AUTOPSIES

One lung involved	30
One lobe involved	11
Both lungs involved	87
Pleural fluid	13
Metastases—53 cases	
Lymph nodes	38
Hilar (tracheobronchial)	27
Mediastinal	11
Cervical	11
Retroperitoneal	3
Pancreatic	1
Thoracic	15
Pleura	9
Pericardium	7
Heart	3
Diaphragm	3
Abdominal	24
Adrenal gland	18
Liver	11
Kidney	8
Spleen	1
Pancreas	1
Omentum	2
Brain	5
Thyroid	1
Skeleton	8
Sternum	3
Ribs	4
Spine	6
Pelvis	1
Long bones	6

Microscopically—The prominent feature is that the interalveolar septa are lined but not invaded by columnar cells which show all degrees of proliferation and form papillary projections into the alveolar lumen The cytoplasm of the cells is clear, may be pink staining due to the secretion of a considerable amount of mucus Nuclei vary in size as do the cells themselves

Opinion differs as to the origin of these cells, whether they come from the alveolar lining epithelium, from the basal cells of the respiratory bronchioles, or from the mesenchymal septal cells This matter is amply discussed by Drymalski and Geever, and Neubuerger and Davis Anatomical developmental studies seem to fortify the opinion that the alveoli are saccular outgrowths of bronchioles and are originally lined by continuous cuboidal epithelial layers In the late intra-uterine stage, the capillary bed develops extensively, interrupting and breaking through the epithelial lining, leaving the epithelium as isolated rounded cells, few in number. Thus, the alveolar lining disappears by disintegration, a physiological phenomenon to allow more rapid interchange of gases between alveoli and blood vessels. The postnatal bronchial epithelium appears to terminate more or less abruptly at the beginning of the alveolar walls which are composed of capillaries in delicate reticular and elastic stroma. In the walls are scattered so called septal cells of mesenchymal origin (epicytes of Clara and Macklin, alveolar cells of Lang). These are fairly characteristic cells with large, oval, pale vesicular nuclei, and abundantly clear cytoplasm which is irregular in contour. They are, in turn, capable of proliferation and transformation (Oppenheim) into epithelial cellular elements. From a practical standpoint, the embryological or histological origin of the alveolar cells is not at all important.

Clinical Features in 155 Cases.—It should be stated that a number of reports do not contain complete clinical data. Incidence is in ratio of 3 males to 2 females, 92 males, 63 females. Only 2 cases occurred in Negroes, 1 in a Japanese. The youngest patient was a 17-year-old girl and the oldest was an 83-year old woman. The peak is reached in the sixth decade. Table II records the age incidence.

TABLE II. INCIDENCE

AGE	NO. OF PATIENTS	SEX	
10-20	1	Male	92
21-30	6	Female	63
31-40	23		
41-50	32		
51-60	58		
61-70	20		
71-83	15		

The family history in the series was not significant, nor was occupation. Two men were subjected to dusty atmospheres, one of these was a molder. Another patient was a sheep rancher, and another a dairy farmer. There was little or no reference to the use of tobacco. Trauma to the chest was considered a possible factor in 1 case.

The past history was not enlightening. Previous respiratory infection was recorded in 18 cases. It was diagnosed as bronchitis in 4 cases, influenza in 5, pneumonia in 3, pleurisy in 2, sinusitis in 3, and tuberculosis in 1. There was a history of repeated infections of an influenzal type over a period of fifteen years in 1 case, of syphilis in 2 cases, 4 had had gastrointestinal disease, 2, heart disease, 1, pericarditis, 3, arthritis, 2, gallbladder disease, and, 1, thyroid disease. Two patients had associated cancer, one uterine and the other a concomitant skin cancer of the face.

The onset in the majority of cases was gradual, but in 22 cases it was ushered in by an acute respiratory attack, diagnosed variously as pneumonitis (12), bronchitis (4), pleurisy (2), influenza (1), rhinitis and sinusitis (4). In 2 cases, the disease was asymptomatic and discovered only in the course of routine physical check-up. The earliest and most constant symptom was a cough and in all but 9 cases was productive of sputum. The sputum was characteristically thin, watery mucoid, white at times, foamy or purulent. The amount varied from 30 c c to 1,500 c c in twenty-four hours In only 4 cases was the sputum scanty Dyspnea was a feature in 81 patients, it was of all grades, usually present only on exertion, but described as severe by 7 Once developed, it was likely to be progressive Weight loss and fatigue were not prominent features Cyanosis was present in 20 patients, hemoptysis in 13, streaking of sputum in 4 Fever was recorded in 20 per cent of the cases and apparently accompanied definite infection of the lung Once the symptoms developed there was no letup, and the clinical condition deteriorated progressively, slowly or rapidly until death, except in those cases relieved by surgery The deterioration was hastened by intercurrent episodes of infection of the lung, and by development of metastases These often added symptoms peculiar to their location as, for example, cerebral disturbance in brain lesions Death came from asphyxia due to replacement of respiratory epithelium, heart failure, or from complicating pulmonary infection

The duration of illness, until a patient came under hospital observation, varied from a matter of several weeks in 9 cases, to five years in 2 cases, and six years in 1 case In 80 per cent, or 123 cases, the duration was less than a year Most of the patients when admitted for institutional care or study were gravely ill and died within six months

Physical signs were dependent on the underlying pathological condition in keeping with the degree of infiltration, consolidation, or pleural effusion Percussion note was that of impaired resonance, dullness or flatness Breath sounds were diminished, occasionally bronchial in quality and at times absent Râles were a more constant finding, of a subcrepitant rather than crepitant type, occasionally sibilant or fairly moist and described as bubbly In several patients who had major heart lesions, the pulmonary signs were overshadowed by edema of congestive heart failure

The blood picture changed with the duration of the disease and the degree of infection In general, anemia was not a factor In only 3 cases was there a red cell count of less than 4 0 million and hemoglobin of less than 70 per cent One of these was found to have only 4 6 Gm hemoglobin and a count of 600,000 cells A primary anemia had been diagnosed ten years before With appropriate treatment the blood count rose to 4 0 million cells in two weeks In contrast, 5 patients had 5 0 million cells with a hemoglobin of more than 90 per cent, 100 per cent, and 104 per cent The white blood counts were evenly divided into two groups, one with a count of 5,000 to 10,000 and the other with a count of 10,000 to 20,000 per cubic millimeter In only 4 cases was the count more than 20,000 Polymorphonuclear cells ranged between 80 per cent and 90 per cent among the highest cell counts, 54 per cent to 80 per cent in the lower Leukocytosis was usually indicative of associated acute inflammation

Sputum examination for malignant cells was recorded as having been made in 42 cases and found positive in 18 Malignant cells were recorded 5 times from pleural fluid, 3 times by aspiration biopsy of the lung, and 4 times in cervical lymph glands

By x-ray examination the earliest lesions appeared as light, patchy infiltrations Later came nodular lesions which were seldom solitary and usually multicentric, often coalescent to the point of forming a mass or massive pneumonic consolidation. Pleural fluid was present in 10 per cent of the cases, ranging in quantity from a small amount to a chest full. In only several cases was atelectasis present. Enlargement of the hilar lymph glands was infrequent. The lesion was demonstrated in one lung 92 times, one lobe 31, as a solitary nodule in 4, and a solitary mass in 5. The x-ray appearance was not pathognomonic of alveolar-cell carcinoma. It was not to be distinguished definitely from adenocarcinoma, metastatic carcinoma, primary tuberculosis, sarcoid granuloma, fungus disease, or bacterial pneumonitis. Therefore x-ray examination of itself was of little aid in establishing the diagnosis of alveolar-cell tumor.

Bronchoscopy and bronchography proved of little value in 21 cases except in a negative way. No tumors were seen in the accessible bronchi. Inflammatory reaction was observed occasionally and some anatomic narrowing or bulging, but no ulceration. Occasionally there was a suggestion of a bronchorrhea.

Differential Diagnosis.—The diagnosis of alveolar-cell carcinoma is difficult to make during life. It can be established with certainty only if characteristic tumor cells are found in either the sputum or pleural fluid by biopsy of lung tissue, secured by aspiration at the time of exploratory thoracotomy, or by biopsy of involved cervical lymph nodes. In the series it was usually established only at autopsy. Alveolar-cell carcinoma was diagnosed correctly in only 32 cases before death, although carcinoma was diagnosed in 23 additional cases. The other diagnoses, preoperatively or ante mortem, were pneumonitis, 21 cases, tuberculosis, 14 cases, pulmonary suppuration, 5, chronic fibrosis, 3, pulmonary edema, 2, sarcoid, 2, metastatic carcinoma, 5, fungus, 3, Hodgkin's disease, 1. In the absence of positive findings, the differential diagnosis hinges on the process of exclusion, for example, by not finding a tubercle bacillus or a fungus in the sputum. Confusion arises because pulmonary disease may be coexistent with the tumor, and may overshadow it. Coccidioidosis may be diagnosed by a positive skin test, histoplasmosis also by a skin test, or by a positive blood culture of *Histoplasma capsulatum* in its yeast phase. Sarcoidosis is a localized lesion involving tracheobronchial and paratracheal lymph nodes without lack of debilitation. Leukemia has a characteristic blood picture, and usually a fine miliary stippling in x-ray appearance. Xanthomatosis usually shows fibrotic and emhysematous components in the x-ray. Secondary neoplasms can be differentiated by cell study and the findings of the extrapulmonic lesions. Hodgkin's disease can be diagnosed by lymph node biopsy.

Treatment.—Inasmuch as alveolar-cell tumor is a malignant neoplasm, treatment other than by radiotherapy and surgery can be at best only palliative. Antibiotics and chemotherapy have their place in relieving the severity of the infection in the bronchi and alveoli, in those cases complicated by bronchiectasis and pneumonitis, and particularly in pneumonitis which often initiates the clinical symptoms. Nitrogen mustard was tried in 5 terminal cases without benefit, but perhaps it has not had sufficient trial. Medical treatment otherwise must be symptomatic to relieve cough, pain, hemoptysis, and to aid digestion and nutrition.

X-ray treatment has been given in 16 cases, in most of them as a palliative procedure None of these patients recovered but there is evidence that radiotherapy may slow the progress of the disease, as in 1 case that I am reporting There was no evidence that it had prevented the development of metastases Used in 3 cases after surgery, one of these was alive and well after five years, after a lobectomy, followed by a pneumonectomy, another was alive after four months, the third was dead in six months This is too small an experience upon which to establish the value of radiation as a postoperative procedure It would be definitely hazardous to employ x-ray to the exclusion of surgery even in early lesions of small extent Alveolar cell carcinoma is apparently not sensitive to x-rays

Surgery, then, is the only method of treatment which offers a chance for recovery, as is true in bronchogenic carcinoma, but probably is not as successful because of the proclivity for alveolar-cell carcinoma to be multicentric and often bilateral in its early stages

Results of Surgical Treatment in 50 Cases—Exploratory operation was performed in 10 cases, segmental resection in 4, lobectomy in 18, lobectomy and lingulectomy in 1, pneumonectomy in 17, exploratory biopsy by needle in 4 Of these 50 cases operated upon, 11 patients are known to be living and well for a period of one to ten years, 1 for six years, 2 for five, 5 for four, 1 for as long as ten years, and one longer than two Five of these 11 had pneumonectomies, and three had lobectomies There were 8 postoperative deaths Eleven died within six months, 4 within twelve months, 8 within two years, and 2 within four years One was lost to follow-up

These results are probably no better than, if as good as, those following surgery for adenocarcinoma or squamous-cell carcinoma of bronchial origin While it is inadvisable to make deductions from a small series, the statistics indicate that pneumonectomy is the operation of choice Segmental resection or lobectomy should be reserved for those occasional cases where there is a localized minimal lesion Opportunity for resection surgery will depend upon early recognition of the tumor Improvement in recovery statistics will also depend upon early surgical attack That a number of these cases have had symptomatic relief and their lives have been prolonged or made more comfortable justifies surgical treatment, but resection for palliation only is questionable

CASE REPORTS

Case 1—M, a 49 year old man who was born and raised on a farm, had had practically nothing to do with animals or sheep *since boyhood* Four years before he remembered having inspected a flock of sheep, but was exposed to them only for a matter of an hour or so He was employed in a grocery business In 1919, he was shot in the chest in a hunting accident The bullet mushroomed, split, and left some fragments in the chest, but he made a satisfactory recovery in a month's time In 1934, the larger bullet fragment was removed from the ensiform cartilage, but small fragments were left in the chest He had had arthritis in the neck for fifteen years following a dental abscess In 1940, he had had double pneumonia which was treated with sulfonamides and he made a satisfactory recovery In 1946, he developed indefinite pains in the chest, and a roentgenogram made then did not show any abnormality In September, 1947, he was reaching over to pick a 10

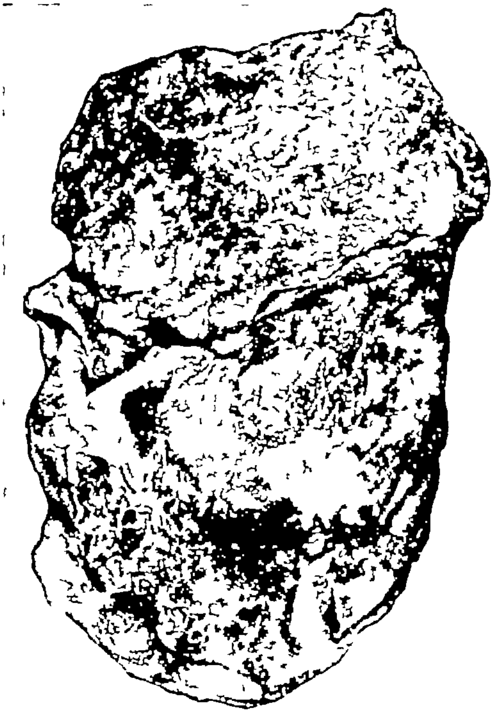

Fig 1 —Case 1 F M Left lung showing a nodule and diffuse infiltration in upper lobe and likewise in lower lobe

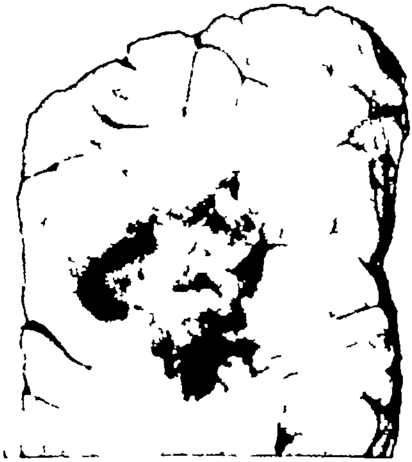

Fig 2

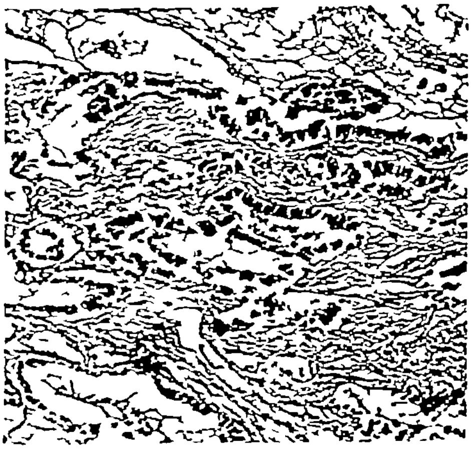

Fig 3

Fig 2 —Case 1 Left temporal lobe of brain showing a large tumor mass with central necrosis

Fig 3 —Case 1 Photomicrograph of the lung tumor showing tall columnar cells in papilla-like projections enclosing spaces filled with mucus (×20 reduced 1/5)

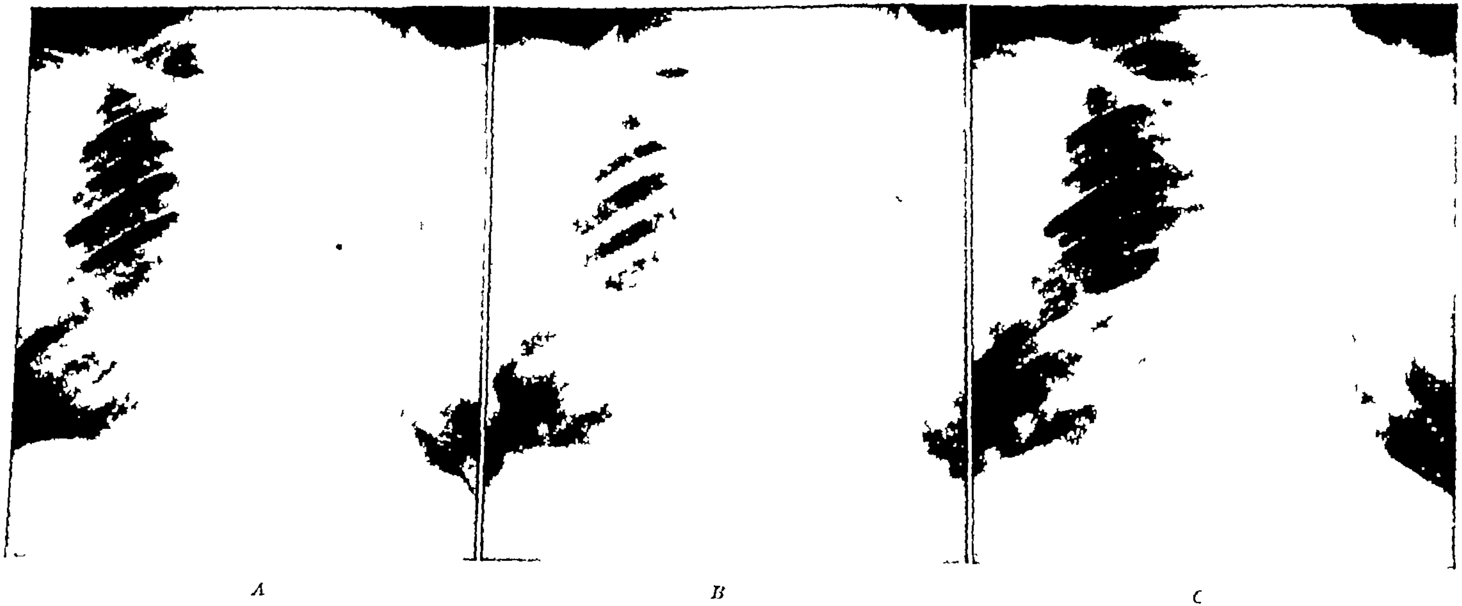

Fig 1 —Case 1 Roentgenograms showing appearances of tumor treated by x ray

A, October 1949 Extensive consolidation of left upper lobe Some infiltration in left lower lobe Few nodules at hilum in lower lobe right lung

B, September 1950 Area left upper lobe smaller less dense Also infiltration in lower lobe and right lower lobe

C February 1951 Area upper lobe larger also nodules in lower lobes pound weight off the floor when he had hemoptysis of more than a cup He was hospitalized and within two or three days had recurrent hemoptysis of about the same amount The diagnosis was pneumonia He was treated with penicillin and sulfonamides for several weeks but was left with a cough and shortness of breath In February, 1948, he was hospitalized at the Research Hospital in Chicago where x ray showed the probability of a tumor of the lung Bronchoscopy was attempted but was not carried out because of rigid arthritis in the neck He was given three x ray treatments over a period of two days, and it was thought that these treatments caused some recession of the tumor, though shortness of breath and a moderate amount of white sputum persisted The patient gained weight up to 233 pounds and then he dieted and reduced to 180 pounds In December, 1948, he developed clubbing of the fingers, and a certain amount of dizziness and palpitation. He was examined by Dr W M Cooper who found dullness in the upper left chest and, by x ray, an upper lobe mass Vital capacity was 3 4 L, 75 per cent of normal There was some enlargement of the liver The blood pressure was 130/80, blood count hemoglobin 90 per cent, R B C, 4 96 million, W B C, 14,900 per cubic millimeter, hematocrit 38, polymorphonuclear leukocytes 58 per cent, lymphocytes 38 per cent, eosin, 4 per cent The sputum was negative for tubercle bacilli. On Feb 19, 1949, he was admitted to my care at the Presbyterian Hospital at which time he had 150 c c mucoid sputum daily, and some left subcostal pain Examination disclosed dullness over the left upper lobe, and x ray showed consolidation of the lobe The sputum contained no tumor cells, and bronchoscopy showed no tumor cells The R.B C was 4.5 million, hemoglobin 93 per cent, weight 200 pounds The diagnosis was carcinoma of the lung Exploratory thoracotomy revealed a large mass in the upper lobe adherent to pleura, and smaller nodules in the upper portion of the left lower lobe The biopsy showed alveolar cell carcinoma The sputum and dyspnea were markedly less when he was treated with Aureomycin X ray treatment was kept up until December, 1950, when he developed head ache and dizziness After an exploratory craniotomy performed in March, 1950, he was found to have brain metastasis He died eighteen months after the onset of pneumonia in 1949, and one year after diagnosis of alveolar cell carcinoma was established

CASE 2—D A, a 66 year old man, was admitted to my service at the Presbyterian Hospital with a fairly nonproductive cough, progressive loss of weight (15 pounds), and loss of strength The sputum was negative for tumor cells Bronchoscopy was negative X ray showed a 6 cm mass in the right upper lung The diagnosis was carcinoma of the lung and chronic pulmonary fibrosis A right pneumonectomy was performed and he died thirty six hours after the operation from asphyxia due to a massive plug in the left main bronchus The microscopic diagnosis was alveolar cell carcinoma

CASE 3—W H, a 58 year old man, had had a cough for five or six years The sputum was mucoid There was a 20 pound weight loss, and substernal pain, and x ray had showed spots on the lungs three years before admission Bronchoscopy was negative An x ray on admission showed extensive nodulation and infiltration of both lungs The diagnosis was pneumoconiosis and tuberculosis Malignancy was not ruled out He died four months after hospital admission, and autopsy disclosed alveolar cell carcinoma One bronchial lymph node was involved

CASE 4—M M, a 64 year old man, was first admitted on April 28, 1950 Two months before, there was an onset of dyspnea on exertion and nausea after eating with a loss of weight of 10 pounds There was an apical systolic heart murmur and the blood pressure was 125/85 In the right upper lobe there were diminished breath sounds and dullness with a few crepitant râles on coughing The sputum was negative for tubercule bacilli and there was predominance of gram positive cocci in chains The sedimentation rate was 16 mm in sixty minutes The hematocrit was 43 per cent X ray showed generalized nodular infiltration involving both lungs, with nodules averaging 5 mm in diameter One consolidation area was located in the middle of the right lung around the hilus The diagnosis was silicosis and atelectasis of the right lung Tuberculosis and carcinoma were not ruled out On the second admission, June 15, 1950, the x ray appearance was as before with addition of fluid in the right chest The fluid, blood tinged, was negative for malignant cells The diagnosis was probable carcinoma of the lung The patient died on July 16, 1951 The autopsy disclosed columnar-cell carcinoma, variant of pulmonary adenomatosis There was metastasis to the pleura, chest wall, pericardium, mediastinum, tracheobronchial lymph nodes, and omentum There was 2,000 c.c of fluid in the pleural space

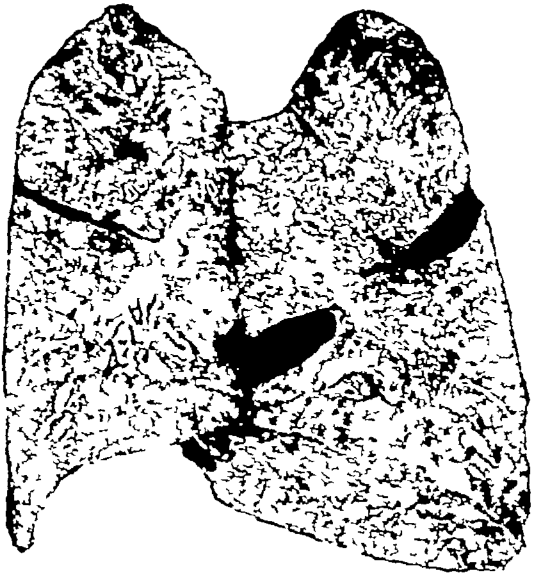

Fig 5—Case 5 M. L Left lung partly hemisected showing diffuse distribution of tumor as light mottled areas over the entire surface.

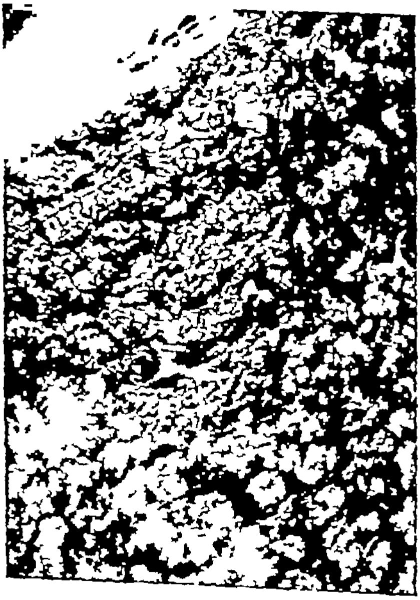

Fig 6—Case 5 Close-up of pleural surface.

CASE 5.—M. L., a 39 year old woman, had had a cough for one year with easy fatigability and dyspnea for six months. She was admitted to the tuberculosis hospital in August, 1949. The sputum was negative for tubercle bacilli. There were cyanosis and substernal pain with a 45 pound weight loss. There was slight hemoptysis one month before. Fine

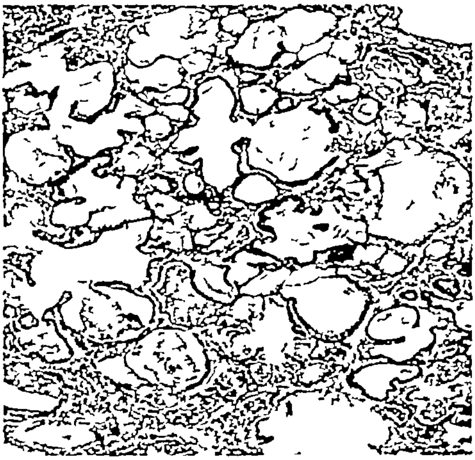

Fig. 7.—Case 5. Photomicrograph of tumor in lung showing large mucus filled spaces lined by columnar cells. (×120; reduced ⅙.)

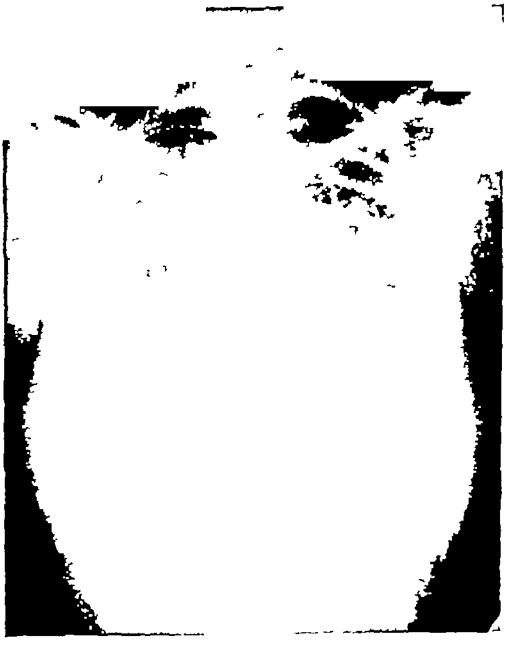

Fig. 8.—Case 5. Roentgenogram: widespread nodules. Infiltration throughout both right and left lung fields.

râles were heard in the bases of both lungs. There were cardiac enlargement and clubbing of the fingers. The blood pressure was 142/90. The vital capacity was 32 per cent of normal. The x ray showed densities throughout the lung fields except in the apices. The x ray diagnosis was pulmonary fibrosis congestion and atelectasis due to cardiac failure. The patient grew progressively worse and she died on Jan 13 1950. Before her death, there was a diagnosis of a nonsuppurative inflammatory process. Autopsy disclosed columnar alveolar-cell carcinoma.

CASE 6—W C., a 35 year-old man had had a productive cough for seven years with occasional aching pain in the chest. A diagnosis was made of minimal chronic pulmonary tuberculosis arrested. The sputum was negative for tubercle bacilli. There was progressive loss of weight fatigue and dyspnea. The x ray revealed apparent activity as soft densities were present in the right lung field with atelectasis in the left lung. Weakness and muscle cramps developed in the legs and finally, paraplegia. X ray showed a *destructive lesion* of the third dorsal vertebra. The sputum was negative for neoplastic cells. The patient died in October 1951. Autopsy disclosed alveolar-cell carcinoma with metastasis to the spine, and right clavicle. There was a small healed scar of tuberculosis in the left first interspace

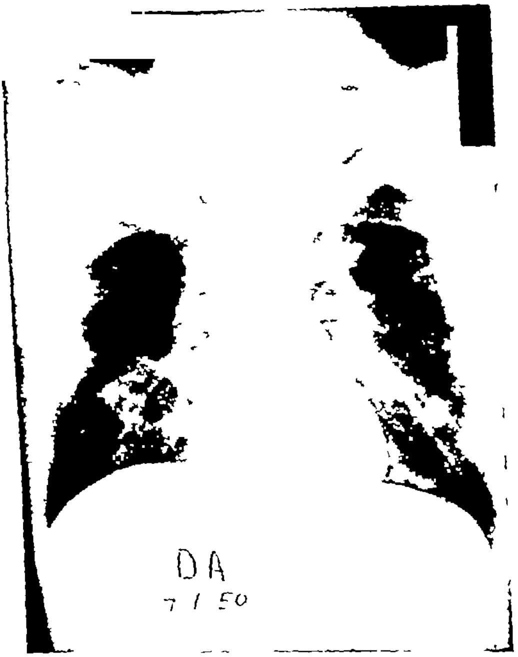

FIG 9—Case 2. D A. Roentgenogram, circumscribed dense shadow characteristic of tumor occupying greater part of right upper lobe.

CASE 7—M. B., a 49 year old man, had had a cough for one month which he thought was due to a cold for which he was given penicillin. The sputum was thin, mucoid and negative for tubercle bacilli and malignant cells. The culture showed a predominance of gram positive cocci. Mycelial forms and Leptothrix were present. The patient had slight dyspnea with a dull aching in the chest. There were no physical abnormalities. The temperature was 99° F, pulse, 90 and respiration 20. Bronchoscopy showed an upper lobe tumor of the left lung which was beyond the reach of the bronchoscope. X ray disclosed a large mass in the left paratracheal position. At operation a mass the size of a baseball was seen which involved the left upper lobe medially. Several subpleural nodules were adherent to and penetrating the pleura. The lesion was considered irremovable. The biopsy proved alveolar columnar-cell carcinoma. The patient died within six months.

CASE 8—A A., a 53 year old man, sought medical advice because of swelling of the terminal phalanges of the hands, feet, and ankles, typical of pulmonary osteorathropathy. There were no pulmonary symptoms. Temperature, pulse, and respiration were normal. Examination of the chest was normal The blood pressure was 150/90 The sputum was negative for tubercle bacilli and tumor cells The red blood count was 4 0 million, hemoglobin 83 per cent, w b c, 4,500, monocytes 54 per cent An x ray examination showed a solitary nodule in the apex of the right lung Bronchoscopy was negative A pneumonectomy was performed The diagnosis was alveolar cell carcinoma For two years, the patient has been alive and well

CASE 9—J K, a 51 year old woman, was admitted to the hospital because of an acute thrombophlebitis in the left leg of two weeks' duration For ten years previously, she had a known myocarditis with dyspnea and a cough The sputum was scanty and of the mucoid type On physical examination subcrepitant râles could be heard at the bases of both lungs The heart was enlarged with an apical systolic murmur The blood pressure was 122/82, temperature, 100° F, pulse, 100, and respiration, 30 The x ray showed that nodular infiltration was extensive in both lungs with coalescence in the left lower lobe which was almost solid The nodules varied from 3 mm to 2 cm in diameter The sputum was negative for tubercle bacilli, with staphylococcus predominating The red blood count was 4 5 million, hemoglobin, 80 per cent, w b c, 20,000 She grew progressively worse with increasing cyanosis and dyspnea Death occurred three months after hospital admission The diagnosis had been metastatic malignancy, and the autopsy proved it to be alveolar cell carcinoma, with metastasis in the tracheobronchial lymph nodes There was an infarct in the spleen and there was thrombosis of the pelvic vessels The heart showed mitral vegetative endocarditis, and hypertrophy of the right ventricle Adhesive pleuritis was present

CASE 10—H. F, a 55 year old man, was well until March, 1952, when he developed a cold and malaise following a squeezing injury to the chest He had a small hemoptysis, and started to lose weight The cough persisted and dyspnea developed He was admitted to the hospital in April, one month later Physical signs in the chest indicated a pleural effusion The expansion of the right chest was small. Breath sounds were absent with flatness The liver was enlarged The temperature was 100° F, pulse, 90, and respiration, 22, r b c, 4 8 million, hemoglobin, 96 per cent, w b c, 11,100, polymorphonuclear leukocytes, 74 per cent. The sputum was negative for tubercule bacilli and tumor cells, and gram positive cocci predominated The pleural fluid contained no tumor cells The sedimentation rate was 38 in sixty minutes The x ray showed a consolidation of the upper and lower right lung fields, with pleural effusion Bronchoscopy was negative An exploratory thoracotomy disclosed a nodular infiltration of the right lower and middle lobes with the lung adherent to the chest wall Biopsy proved alveolar columnar cell carcinoma The patient died one month after the operation

CONCLUSION

From this record it is evident that alveolar-cell carcinoma is a rare and highly malignant form of cancer which runs a fatal course within two or three years It is a tumor which cannot be diagnosed often enough in its early stages to permit early and successful attack Thus far, surgery, and not radiotherapy, is the only treatment for prolonging and saving life Two patients have lived longer than five years following resection surgery

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IMPROVED INSTRUMENT FOR TIMED VITAL CAPACITY

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VITAL capacity is one of the oldest measurements of pulmonary ventilation In recent years the test has been critically analyzed by a number of investigators Bjork[1] and others have suggested that the test be eliminated The chief count against the test is the wide range of normal values Formulas for predicting normal vital capacity are available [2] [4] but a single test may deviate as much as 20 per cent from the calculated figure On the other hand, serial determinations of the vital capacity are especially useful in evaluating a patient's ventilatory status from time to time Thus, the observed changes become more important than the single observation or deviation from normal The validity of serial studies is based on the fact that repeated vital capacity tests from day to day or month to month will yield almost identical results on a normal subject [5] A series of 24 convalescing tuberculosis patients with stable x-rays were tested in our laboratory and retested after an interval of three months Our results showed a difference of +3 6 per cent between the averages of the first and second determinations and a range of +11 per cent to –9 per cent We have used the test extensively for determining the amount of functioning lung lost as a result of pulmonary resection for residual tuberculous disease [6]

Recently, Gaensler[5] [7] [8] has popularized the timed vital capacity This is a dynamic test designed to give the amount of the expired air in relation to time As generally performed, the test gives the amount of air expired in one, two, and three seconds, as well as the total vital capacity, from which the percentages may be calculated In normal subjects the percentage expired in the first second is 83 per cent, in two seconds 94 per cent and in three seconds 97 per cent [5] The test is useful in separating patients with obstructive insufficiency from those with restrictive ventilatory insufficiency For example, the emphysematous patient often has a total vital capacity within normal range, but the timed vital capacity demonstrates prolonged expiration

At our hospital, patients scheduled for pulmonary resection receive ventilatory screening tests consisting of the spirographic pattern as described by Baldwin,[4] maximum breathing capacity,[4] and one-breath O_2 test for intrapulmonary mixing [9] During the past year, if the spirogram suggested air trapping or if the maximum breathing capacity was reduced and the tracing showed elevation to hyperinflation level, the Gaensler timed vital capacity test was performed. Under these circumstances the timed vital capacity like-

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wise proved to be abnormal Furthermore, most of the surgical patients with greatly prolonged timed vital capacity have shown emphysema in the resected portion of the lung[6]

The vitalometer, as recommended by Gaensler,[7] is a standard Collins vital capacity instrument with a 7 L bell suspended in a water bath By means of an electrical device, the amount of air expired on maximum, rapid expiration is determined for one, two, and three seconds Percentage is calculated by dividing these figures by total vital capacity We have found the apparatus to be reliable, but there are certain features which are undesirable First, the apparatus does not measure the time necessary to expel the first 200 to 400 c c of air This is due to the design of the timing device which is not activated until this amount of gas displaces the bell upward Thus, criterion number 2 of Gaensler[8] is not met This states that the instrument should permit initiation of the timing cycle by the beginning of the patient's expiratory effort The speed with which the patient initiates expiration under conditions of work is an important factor in pulmonary ventilation The maximum breathing capacity is greatly influenced by the rapidity of the initial phase of expiration.[10] A second factor of concern to the patient is the necessity of repeating the test at least two times for each second in order to ensure data with maximum accuracy This is not only tiring to some patients but consumes the technician's time Third, the apparatus provides no spirographic record for future study and comparison

These difficulties may be overcome by adapting a recording system to the vitalometer A low torque potentiometer* is fitted over the shaft of the pulley wheel (Fig 1) The activating current is obtained from a 1 5 volt battery connected to a rheostat The output of the potentiometer is led to a D C amplifier in a Sanborn recorder run at a speed of 2 5 cm per second Fig 2 shows the electrical diagram. The curve obtained is practically linear (Fig 3), and gives the volume of expired air in relation to time Calculation of the timed vital capacity is easily accomplished by reading the volumes for each second off the curve after projecting perpendicular lines for one, two, and three seconds from the time line Fig 4, *A* illustrates a normal vital capacity curve On the ordinate at the left is shown the standardization of 0 and 5,000 c c Five large squares along the base represent one second Fig 4, *B* shows an abnormal curve obtained from a patient with pulmonary emphysema, proved by resection of the lung

To ensure accuracy, the apparatus was tested for resistance to rapid air flow and this was found to be negligible (2 cm of water pressure at rate of 6,000 c c/sec) Thirty patients with vital capacities varying between 1,500 c c and 5,000 c c were selected to perform the vital capacity test on the vitalometer, on a Collins respirometer, through a high velocity valve into a meteorological balloon, and on a special Emerson low resistance gas volume meter Care was taken to vary the sequence in which the four instruments were used No corrections for temperature, pressure, and humidity were made as the four tests on each individual were performed under the same conditions Table I shows the results of these tests It is evident that the vitalometer yields accurate results in all clinical ranges Furthermore, duplicate volume curves were carried out on 30 patients, allowing a few minutes between the first and second test There was very little difference between the first and second total vital capacity tests The correlation coefficient (r = 97) between these indicates a high degree of reliability between repeated testings The differences between the duplicate values obtained for the first, second, and third second timed vital capacity were likewise extremely small When subjected to statistical analysis, the correlation coefficient for the first second was r = 95, second second, r = 97, and third second, r = 95

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*Giannini No. 2 270 degrees low torque, 100 000 ohm.

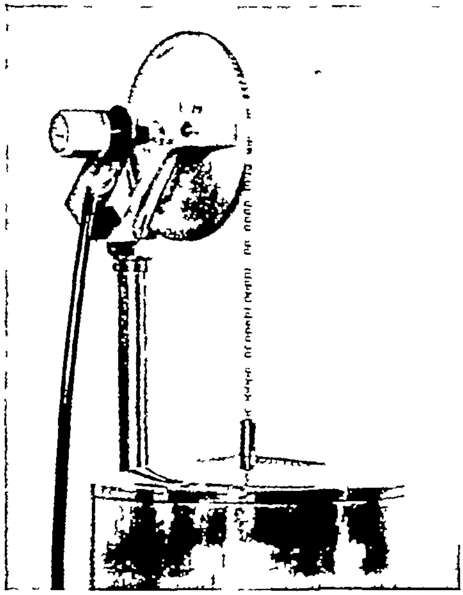


Fig 1 —Potentiometer fitted to vitalometer

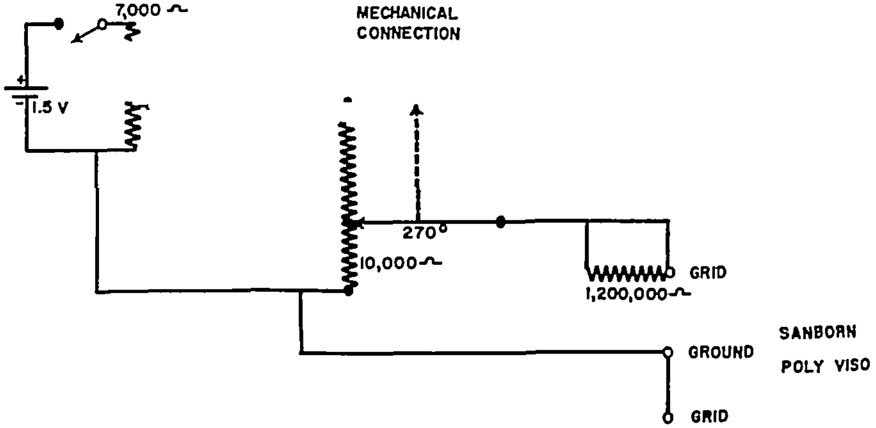


Fig 2 —Diagram of potentiometer circuit

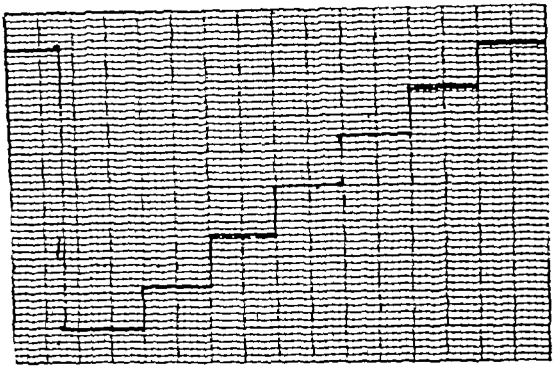
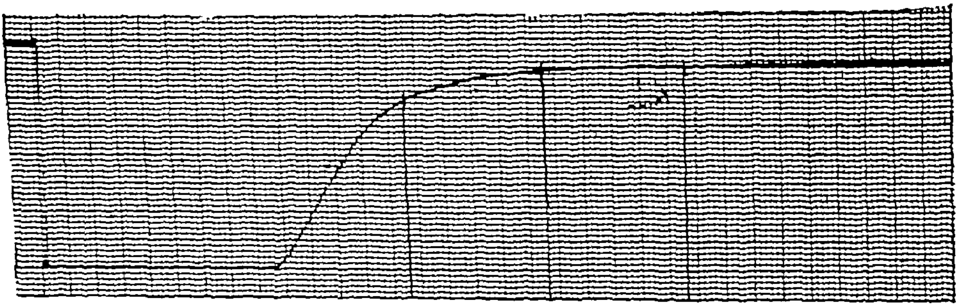
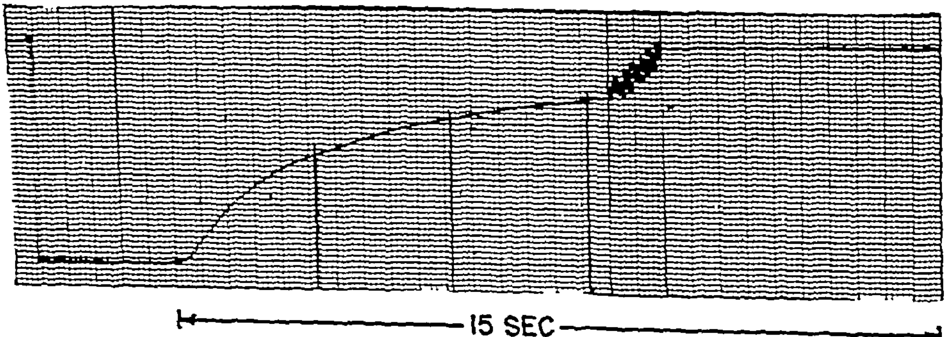


Fig 3—Each step represents addition of an equal amount of gas to vitalometer



TOTAL V C 4438cc, Ist SEC 83%, 2nd SEC 97%, 3rd SEC. 99%

Fig 4A—Normal timed vital capacity



TOTAL V C 4800cc, Ist SEC 50%, 2nd SEC 67%, 3rd SEC 77%

Fig 4B—Abnormal timed vital capacity

TABLE I COMPARISON OF FOUR TYPES OF VITAL CAPACITY INSTRUMENTS

	NO OF PATIENTS	VITALOMETER	RESPIROMETER	EMERSON	BALLOON
AVERAGE VITAL CAPACITIES	30	3,748 c c	3,530 c c	3,583 c c	3,747 c.c
Group 1 1,500 3,000 c c	8	2,621	2,427	2,456	2,556
Group 2 3,000 4,000 c c	8	3,368	3,247	3,218	3,415
Group 3 4,000 5,000 c c	14	4,609	4,322	4,427	4,617

SUMMARY

1 The value of the vital capacity test for evaluating changes in pulmonary ventilation is discussed

2 A modification of the vitalometer is described which utilizes a potentiometer to obtain a timed volume graph

3 The advantages of this modification are as follows

- a The method records air flow from the moment expiration begins
- b Only one expiratory effort is required to obtain data from which one , two-, and three second timed vital capacity percentage is calculated
- c A small permanent record is obtained which is accurate and easily interpreted

4 The convenience and simplicity of this instrument extend the usefulness of the timed vital capacity in screening patients before pulmonary surgery

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty sixth Annual Meeting of the American Association for Thoracic Surgery will be held May 7, 8 and 9, 1956, in Miami Beach, Florida. Headquarters will be at the Hotel Fontainebleau

Requests for Hotel Reservations

These should be mailed directly to Mr Jack Slone, Director of Sales, Hotel Fontainebleau, Miami Beach, Florida. Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure If accommodations are desired elsewhere in Miami Beach, please communicate directly with the hotel of your choice

Thoracic Surgical Forum

The Thoracic Surgical Forum will be continued as a special session at the 1956 meeting The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies and modified or new surgical techniques The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferral to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper

All Thoracic Surgical Forum papers will be published together in one issue of the JOURNAL. Maximum length 3000 words without illustrations If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of all papers at the 1956 meeting must be received on or before Dec 15, 1955, otherwise they will not be considered by the Program Committee

Abstracts should be labeled "For Thoracic Surgical Forum," or "For Regular Program " The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper

Five, repeat, five copies of *each* abstract must be sent to the Secretary of the Association, Dr Paul C Samson, 3959 Happy Valley Road, Lafayette, California They should not be sent to the Editor

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in the JOURNAL OF THORACIC SURGERY

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis *The films themselves,* together with descriptive material concerning length of presentation, etc, must be received by Dr Julian Johnson, University Hospital, 3400 Spruce St, Philadelphia 4, Pa, before Dec 15, 1955

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec 15, 1955, otherwise, the applications will be deferred for consideration until the 1957 meeting

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

The Journal of Thoracic Surgery

Vol. 30 | September, 1955 | No. 3

Original Communications

PLEUROBILIARY AND BRONCHOBILIARY FISTULAS

Herbert D. Adams, M.D.

Boston, Mass.

MY FIRST experiences with biliary communications with the pleural space or with a bronchus were associated with abdominothoracic war wounds. Penetrating wounds which lacerated the pleura, lung, diaphragm, and liver occasionally resulted in direct communications between the biliary tract and the pleura or a segmental bronchus. Such complex wounds produced a marked extravasation of bile into the pleural space, which I have termed "bilithorax," or the profuse expectoration of bile, which I have termed "biliptysis." It is essential that both of these conditions be recognized and understood in order for them to be treated adequately. Bilithorax produces a rapid, progressive, and dangerous intrapleural pressure. A thoracentesis that produces bile should be followed immediately by trocar thoracotomy and closed intercostal catheter suction drainage. If, however, the patient is coughing up copious amounts of bile, it becomes even more urgent to establish adequate drainage of this same type in order to prevent a fatal necrosing bronchitis due to the action of the bile plus secondary infection throughout the bronchial system. Large doses of broad coverage antibiotics should be started immediately and shifted as soon as possible to specific antibiotics when antibiotic sensitivity studies have been rushed through. When the intrathoracic dynamics are fully stabilized and the biliptysis is controlled to a satisfactory degree, prolonged catheter suction drainage plus antibiotics will frequently permit these fistulas to heal completely. If extensive lung or liver damage is present, however, secondary surgery may be necessary to close the fistula by either pulmonary resection or debridement and open drainage of the liver. In short, each case presents special problems of an abdominothoracic cavitary and visceral relationship which must be handled with considerable care and judgment.

From the Department of Surgery, The Lahey Clinic, Boston, Mass.

Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City, New Jersey, April 24 to 26, 1955.

Among civilian patients, however, pleurobiliary and bronchobiliary fistulas are very rare, they are more insidious and more chronic in nature, but still *present serious and complex surgical problems. Obstruction in any of the biliary* ducts, that is, cystic, common, or hepatic ducts, may, in conjunction with calculus, secondary infection, or surgical injury, result in the establishment of a fistulous communication between the gall bladder or any of the ducts with the perihepatic and subdiaphragmatic spaces (Fig. 1). With secondary infection and an increasing collection of bile under pressure in contact with the diaphragm, erosion through this structure finally takes place. If the pleura is free, a pleurobiliary fistula is established and a bilithorax and empyema rapidly develop in all of the unfused pleural space.

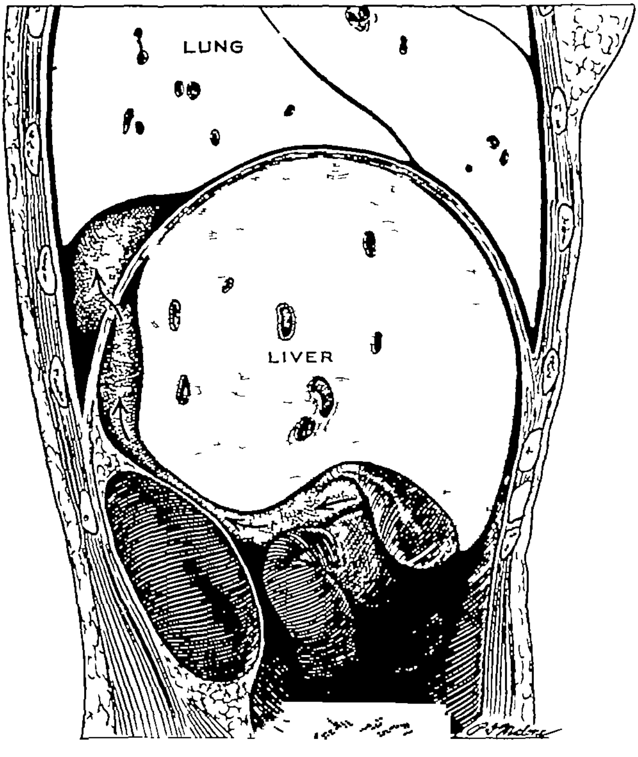

Fig. 1.—Sagittal section showing the cavitary and visceral relationships of the communicating pathway between biliary tract and pleural cavity.

Under these conditions the symptoms are those of a massive and progressive tension hydrothorax. Infected bile is obtained on thoracentesis, with subsequent rapid reaccumulation. As in the war casualties, the treatment consists of immediate closed intercostal suction drainage and the administration of antibiotics. *When the intrathoracic dynamics are stabilized and the patient's condition* permits, the pathological condition in the biliary tract must be corrected surgically.

We have had 2 cases of this type resulting in pleurobiliary fistulas.

CASE REPORTS

CASE 1—A 59 year old man was admitted to the clinic whose chief complaints were of a draining sinus in the right posterior chest and general debility An acute abdominal condition and generalized peritonitis had developed and at another hospital he had undergone drainage of the peritoneal cavity, on the assumption that he had a perforated appendix. During the immediate postoperative period what was thought to be pneumonia and an empyema developed. Three weeks following the original abdominal drainage a rib was removed in the right posterior chest wall and an abscess drained This sinus in the chest wall had continued to drain large amounts of pus and bile since the original drainage, although at times this drainage decreased and chills, fever, and malaise developed, followed by a more profuse spontaneous drainage of bile and pus from the chest wound after which there was temporary improvement During this time he had lost 15 pounds with an associated loss in strength and appetite

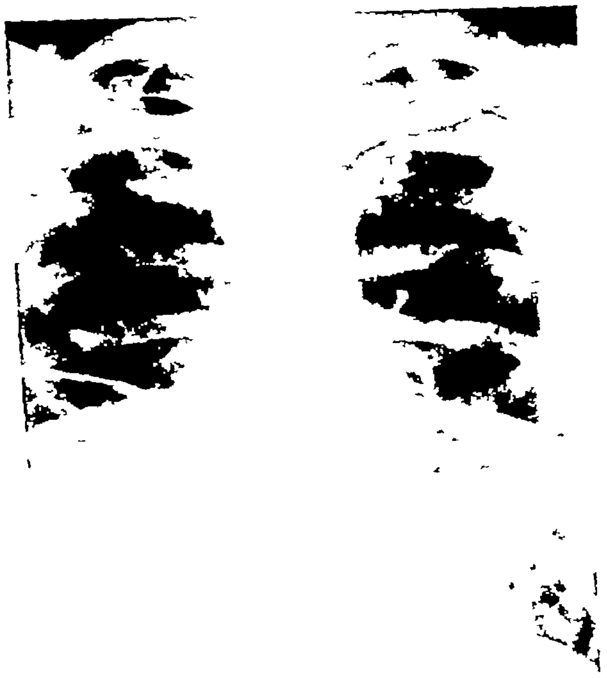

Fig 2—Case 1 The elevated right diaphragm and pleural reaction associated with pleurobiliary fistula are shown

On physical examination the patient was well developed but showed evidence of long standing illness Examination of the chest revealed crepitant râles at the right base posteriorly with definitely diminished excursions of the diaphragm. The diaphragm was elevated posteriorly to the level of the seventh rib In the right posterior axillary line at the level of the eighth rib there was a draining sinus which discharged a cloudy yellow material characteristic of infected bile Fluoroscopy and roentgenologic examination of the chest showed the diaphragm considerably elevated and obscured and no motion could be seen (Fig 2) There was considerable thickening of the pleura throughout the right thorax A Graham test showed nonfilling of the gall bladder A catheter was placed in the sinus tract and Diodrast injected which demonstrated a sinus leading up under the diaphragm ending somewhere in the region of the liver Therefore it was thought that *perhaps the abscess had its origin intrahepatically and subdiaphragmatically* Since there was no question that a communication was present between the biliary tract and the *pleura, an abdominal operation* was performed and, after a difficult dissection, a perforated gall bladder was found which communicated with the sinus in the pleural space The gall bladder was *removed and the common duct* explored and drained Following this operation, he made a very satisfactory recovery and the pleurobiliary fistula and the residual *empyema cavity filled in promptly*

CASE 2—The second patient was a 65 year old man who had a typical acute attack of cholecystitis, with pain in the right upper abdominal quadrant with tenderness, and an elevated temperature which did not subside He was operated on as an emergency case and a gangrenous, ruptured gall bladder was drained Following this operation, he continued to have chills and fever Roentgenograms of the chest showed a marked elevation of the right diaphragm with basal pleuritis and atelectasis Bronchoscopy was negative Three weeks after the original drainage, a combined bilithorax and empyema were drained, with the ultimate establishment of a pleurobiliary fistula which continued to drain bile after all of the acute infection had subsided When his condition permitted, another abdominal operation was performed The sinus tract was found to communicate with the pleura, the subdiaphragmatic space, and to a ruptured gall bladder, with persistence of the sinus due to a common duct stone This stone was removed and the patient made a satisfactory recovery The pleurobiliary fistula closed spontaneously

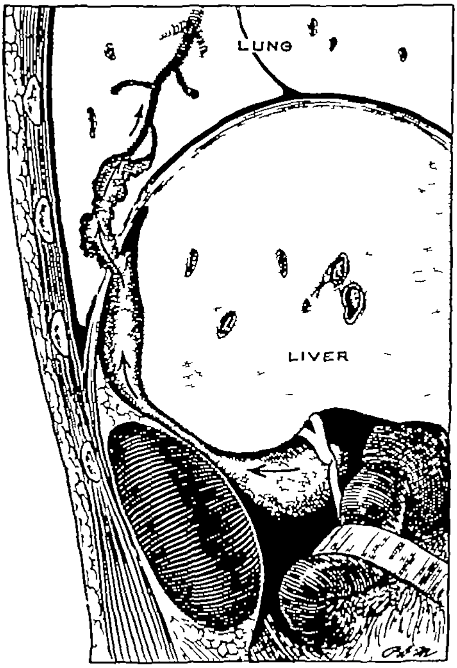

Fig 3—Sagittal section showing biliary tract communicating with posterior basal segmental bronchus

However, if the pleura is fused over the point of perforation at the time of rupture through the diaphragm of the bile which is under pressure beneath *that structure, this infected bile will rapidly penetrate* the lung and enter a secondary bronchus, producing a bronchobiliary fistula and profuse biliptysis (Fig 3) In this situation it is essential to establish immediate drainage of the subdiaphragmatic space in order to prevent a fatal necrosing bronchitis and associated pneumonia due to the flooding of the bronchial tree with infected bile This is accomplished best by direct drainage across the costophrenic pleural sulcus through the bed of the eleventh rib, suturing the costophrenic pleural surfaces together before incising the diaphragm (Fig 4) as I described in an earlier article on subdiaphragmatic abscess * With this type of drainage and adequate chemotherapy, and when the acute bronchial reaction and inflammation have subsided and expectoration of bile has become greatly reduced, the appropriate surgical procedure to relieve the biliary obstruction which is the

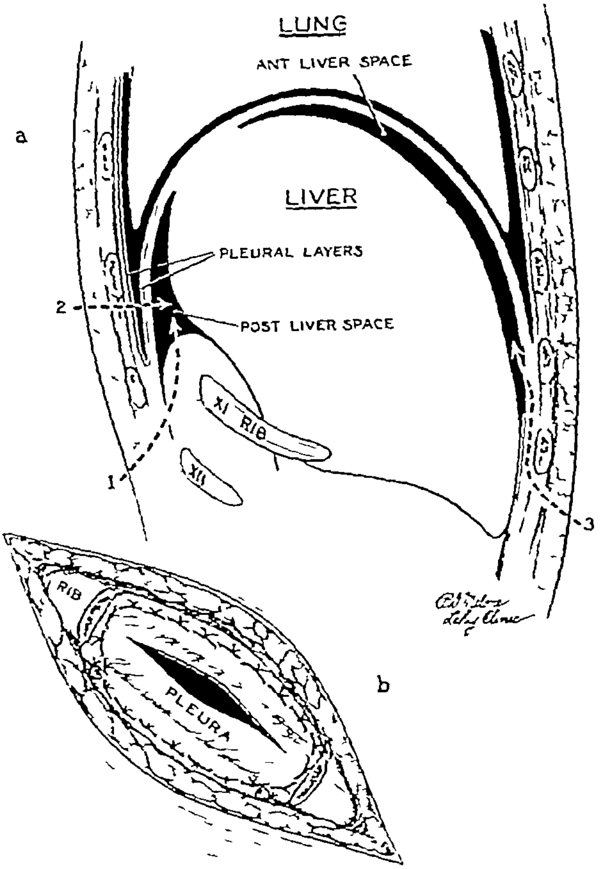

Fig 4 —a Sagittal section to show approach to subdiaphragmatic abscess by way of (1) the twelfth rib (2) the eleventh rib and (3) the subcostal anterior approach Arrows represent course of drain *b* Detail to show method of obliterating the costophrenic pleural angle by overlapping sutures between the parietal and diaphragmatic pleura. (From S Clin North America June 1948 W B Saunders Company)

basic cause of the fistula must be carried out In our 2 cases, the bronchobiliary fistulas were caused by common duct strictures I will not go into the discussion of the complexities of the repair of common duct strictures in this paper It is interesting to note that in these 2 cases we were not able to demon-

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* Adams H D The Surgical Management of Perihepatic and Subdiaphragmatic Abscess S Clin North America 28 685 692 1948

strate the entire course of the fistulous tract by bronchogram, cholangiogram, or at operation Presumably as soon as external drainage has been established, the tract that persists is very small and of a circuitous nature as it passes through and around the various anatomical structures involved However, in both instances, the bronchogram demonstrated a bronchiectatic right posterior basal segmental bronchus as the communicating bronchus

In one of our cases successful repair of the stricture of the common duct was followed by gradual diminishing of the biliptysis and by spontaneous closure of the fistula, finally In the other case, although there was much improvement, intermittent cough productive of bile persisted and eventually a right lower lobectomy was done with final cure of the bronchobiliary fistula The following reports are summaries of these 2 cases

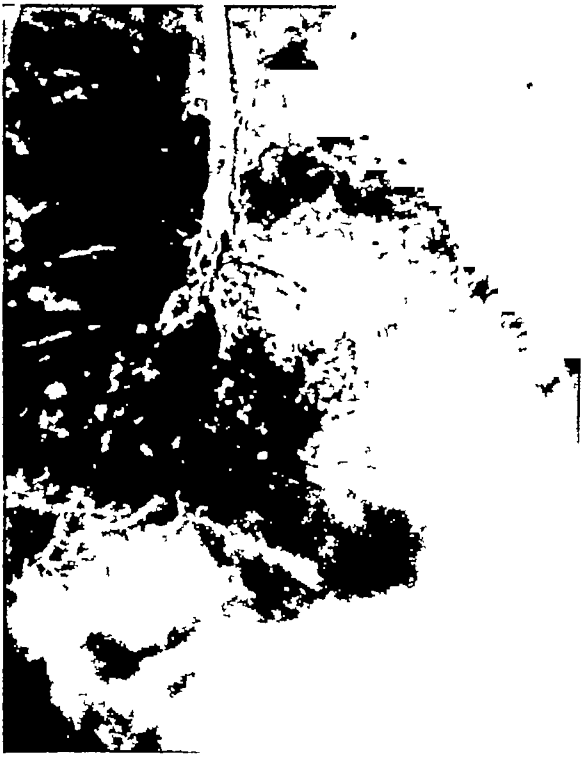

Fig 5——Case 3 Bronchogram showing bronchiectatic posterior basal segmental bronchus which is the communicating bronchus of the bronchopleural fistula

CASE 3—A 35 year old woman had a cholecystectomy at another hospital, followed by jaundice and a stricture of the common bile duct In addition, a repair of the stricture by a choledochoduodenostomy had been attempted elsewhere before she came to the clinic

After admission here, the patient was carefully prepared and, at exploratory operation, was found to have a stricture involving the common duct up to the level of bifurcation of the hepatic ducts A repair was attempted over a T tube Approximately three weeks after operation, however, the T tube became dislodged She was operated on again and this time a repair was carried out over a bouncing clay Y tube She made a good recovery and her jaundice cleared, but approximately three months later chills, fever, and a cough developed, and the possibility of pneumonia at the right lung base was considered Shortly thereafter she began to cough up pus, necrotic tissue, and bile This expectoration became profuse and was almost pure bile She was readmitted to the hospital and bronchoscoped, a bronchogram showed a bronchiectatic posterior basal segmental bronchus but the actual tract communicating with the biliary tract could not be visualized (Fig 5) With bed rest and very adequate chemotherapy, the biliptysis gradually diminished and finally cleared up

In this instance, the bronchobiliary fistula healed spontaneously, the patient has continued to do well and to date has had no recurrence of biliary obstruction or bronchobiliary fistula

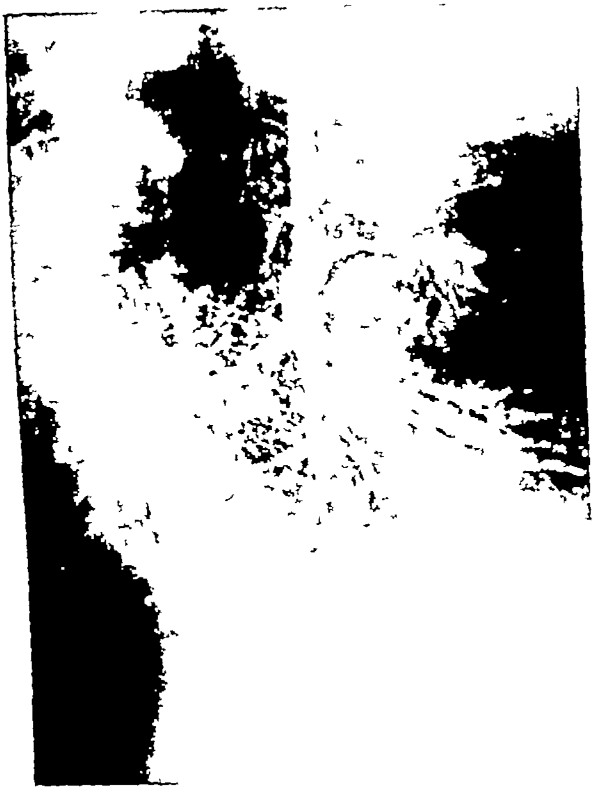

Fig 6—Case 4 Bronchogram showing bronchiectatic posterior basal segmental bronchus which is the communicating bronchus of the bronchopleural fistula

Case 4—A 60 year old woman gave a history of having had a cholecystostomy, previously, and later a cholecystectomy, both done elsewhere, following which numerous attacks of obstructive jaundice developed Finally, during one of these spells of biliary obstruction, a pneumonic process of the right lung base developed and a bronchobiliary fistula was established, with a profuse biliptysis After she was admitted to our care, one attempt was made to repair the stricture, which involved the bifurcation of the hepatic ducts over a T tube, but within a few months this failed to control the stricture and biliptysis recurred She was readmitted and finally the stricture was repaired, utilizing a bouncing clay Y tube Following this operation, her condition improved considerably and the jaundice cleared, but she continued to have intermittent episodes in which biliptysis recurred Bronchoscopy was performed and a bronchogram showed a bronchiectatic posterior basal segmental bronchus which undoubtedly communicated with the fistula (Fig 6)

Therefore, in view of the chronicity of the problem, a right lower lobectomy was carried out. Recovery was uneventful and neither the biliary obstruction nor the bronchobiliary fistula has recurred

SUMMARY

Pleurobiliary and bronchobiliary fistulas are caused by penetrating abdominothoracic wounds, obstruction of the biliary ducts, that is, the cystic, common, or hepatic ducts, in conjunction with calculus, secondary infection, or strictures due to surgical injury The acute phase must be treated promptly by adequate drainage to correct the intrathoracic dynamics or, in case of bronchobiliary fistula, to prevent a serious necrotizing bronchitis and pneumonia Secondary operations on the biliary tract and even pulmonary resection may be necessary to cure these serious and unusual conditions

DISCUSSION

DR GUSTAF E LINDSKOG, New Haven, Conn —I enjoyed Dr Adams' paper particularly, because in the past year we have seen one case of biliary bronchial fistula The patient had had a cholecystectomy performed in another hospital which was followed by a long period of external bile drainage and eventual production of typical biliary sputum He expectorated more than 500 c c of frank biliary material in twenty four hours After appropriate supportive measures, a laparotomy was performed and a very large common duct stone was removed Thereafter the "biliptysis" disappeared readily, and in a long term follow up his condition remained good

In civilian and spontaneous cases, I think the point to emphasize is that the primary method of attack is laparotomy, rather than thoracotomy

DR LEO ELOESSER, San Francisco, Calif —It is a bit shocking to hear from the lips of a Bostonian so bastard a term as "biliptysis," which joins Greek and Latin in unholy wedlock

One sees biliary bronchial fistulas, or did see them, in countries where abscesses of the liver are frequent It is characteristic of them that they follow the midline, proceed along the hepatic ligament to the mediastinum and thence to the bronchi I agree with Dr Lindskog that ordinarily the best way of attack is via the abdomen, when the abdomen is opened and the abscess drained, the flow of bile will cease

DR LAURENCE H RUBENSTEIN, Chicago, Ill —I have enjoyed this excellent discussion of a rare surgical problem, and I merely wish to discuss a case in point

The patient, a 23 year old man, had a fluctuant swelling in the epigastrium This was incised and a draining biliary fistula resulted An abdominal exploration was carried out to inspect the possible cause of the draining bile fistula The common bile duct was patent The fistulous tract led directly into the left lobe of the liver Dense adhesions were noted between the left lobe of liver and the left diaphragm The cause of the fistula was not apparent and the fistulous tract was closed.

After closure of the tract, the patient had severe episodes of coughing and he expectorated bile He became toxic and showed signs of pneumonitis in the lingula segment of the left upper lobe Two episodes of massive hemoptysis led us to do a lingulectomy as a lifesaving measure The bronchobiliary fistula was surrounded by dense adhesions binding the lung to the diaphragm. The specimen showed bronchiectatic changes with hemorrhage Subsequently the abdominal fistula recurred and I am told that another abdominal exploration was carried out and again the cause of the fistula was obscure The jejunum was anastomosed to the fistulous tract which came directly from the left lobe of the liver As far as I know today, the patient has been well

DR RICHARD B NOLAN, New York, N Y.—I take this opportunity to report another case of bronchobiliary fistula which was seen at the Triboro Hospital in New York.

The patient, a 61 year old woman, had had a cholecystectomy for chronic cholecystitis and cholelithiasis twenty five years before. This was followed shortly by evidence of obstructive jaundice. At re exploration, a stricture of the common duct was discovered and resected and primary anastomosis was performed. During the ensuing twenty four years she had occasional bouts of cholangitis without jaundice and usually responded promptly to one or two injections of Demerol. On this admission, however, she complained of a chronic cough of two weeks' duration, productive of copious quantities of bile stained sputum and presenting the signs and symptoms of cholangitis and pneumonitis.

There were areas of pneumonitis involving the right lower lobe with a markedly elevated diaphragmatic leaflet and bronchiectasis involving the right lower lobe. Preoperative cholegrafin studies failed to outline the intra or extrahepatic duct system. At operation a markedly dilated common duct was filled with clusters of stones of varying size with no evidence of stricture. A choledochotomy was performed and cholangiograms at this time revealed a tremendously dilated common duct with excellent visualization of both hepatic ducts and evidence of numerous stones in each. The distended hepatic ducts could be followed up to the level of the diaphragmatic leaflet but no visualization of fistulous communication was noted. A large-sized T tube was inserted and the patient was discharged.

She did well for three or four months and was then readmitted with evidence of secondary obstruction above the T tube undoubtedly due to stones. Choledochoduodenostomy was done at this time and a gastrointestinal series taken postoperatively showed a rapid reflux of barium into a much smaller common duct and hepatic duct system. The bronchobiliary fistula has remained closed since the initial drainage of the common duct.

This case is somewhat unique in that a superior space fluid collection was never demonstrated either on x ray or at exploration. It should be noted that decompression of the common duct obstruction via the biliobronchial fistula accounted for the absence of clinical jaundice. A widely patent choledochoduodenostomy has effectively decompressed the common duct, now free of stones on x ray.

DR ROBERT L. ANDERSON, Tulsa, Okla.—I have been particularly interested in the treatment of bronchobiliary fistulas since we are in the process of reporting a case which was treated at the Valley Forge Army Hospital last year. Since Dr J E Graham reported the first case of bronchobiliary fistula, secondary to trauma in 1894, six cases have been reported in the literature, our case being the seventh. My remarks this morning will be confined to bronchobiliary fistulas due to trauma. The diagnosis of such a complication is relatively simple since all these patients spit up large quantities of bile in the sputum.

The conditions that are associated with bronchobiliary fistulas are empyema, subdiaphragmatic abscess and liver injury with secondary hemorrhage from the liver. Only one of these cases showed evidence of obstruction of the biliary tree.

In the treatment of such cases due to trauma, biliary obstruction is not an important factor, while in the bronchobiliary fistulas due to other causes the biliary obstruction, be it partial or complete, is an extremely important factor in the cause and treatment of this condition. The biliary obstruction must be relieved if treatment is to be successful. This is not true in the bronchobiliary fistula secondary to trauma. If biliary obstruction is present, it is usually of a transient nature and is caused most commonly by bleeding into the biliary radicals. Such a situation rarely plays a prominent part in a particular case, and decompression of the biliary tree is rarely necessary.

In a review of these seven cases, one case had a simple drainage of the empyema cavity; three aditional cases had drainage of the empyema cavity and of the subdiaphragmatic abscess; one in addition to the drainage of the empyema cavity and the subdiaphragmatic abscess, had a bronchobiliary fistula closed primarily. The sixth had drainage of the empyema cavity and the subdiaphragmatic abscess, together with exteriorization and packing of the liver bed, the last and seventh case had drainage of the empyema cavity and of the subdiaphragmatic abscess, decompression of the biliary tract, and closure of a bronchopleural fistula It is interesting to note that the most important consideration in the treatment of these cases is an adequate and dependent drainage of an empyema cavity or a subdiaphragmatic abscess, if such is present In only one case was it necessary actually to close the bronchobiliary fistula Packing of the liver was necessary in only one case, and decompression of the biliary tract was necessary in one case

In summary, I would like to say that most traumatic bronchobiliary fistulas will respond to the simple drainage of the empyema cavity and/or of the subdiaphragmatic abscess if present Closure of the fistula, packing a severely damaged liver, or biliary decompression is occasionally necessary A proper surgical attack in this condition is highly successful All seven patients recovered without sequelae The bronchial tree shows no permanent damage In those cases in which the bronchial tree was studied by means of bronchogram and by bronchoscopy, no permanent damage was noted and no treatment was required

In closing, I would like to say that I enjoyed Dr Adams' instructive and interesting paper very much

DR HERBERT D ADAMS (*Closing*)—I appreciate very much the comments of the various discussers One of the most interesting aspects of this condition is the occasional chronicity of some of these cases and the fact that they can go for years with biliptysis once the original associated acute infection is controlled I agree entirely that the primary approach to these is preferably by the abdominal route to correct the basic biliary disease, although if there are severe structural changes in the lungs, it will become necessary to do a secondary pulmonary resection I also appreciate Dr Eloesser's remarks We had considerable difficulty in deciding just how to coin this word and also how to pronounce it

STAPHYLOCOCCAL PNEUMONIA AND EMPYEMA IN INFANCY

W E BLOOMER, M D (BY INVITATION), S GIAMMONA, M D (BY INVITATION),
G E LINDSKOG, M D, AND R E COOKE, M D (BY INVITATION)
NEW HAVEN, CONN

DURING the past three decades there has been an increase in the relative incidence of primary staphylococcal pneumonia and empyema in infants,[6 11 21] which is apparently related to the widespread use of antibiotics It has become the most common type of empyema at this early age[9, 21] The pneumonia may take the form of a fulminating process with such overwhelming toxicity that the patient succumbs in a day or two presenting at post-mortem examination, lungs with areas of massive consolidation intensely hemorrhagic in appearance[9] More commonly, there is a less fulminating type of infection wherein multiple tiny abscesses tend to form around smaller bronchi in the peripheral lung These necrotizing foci account for the high incidence of empyema and pneumothorax associated with this disease

Radiographic findings may be distinctive but are not pathognomonic Those of most diagnostic help[5] are (1) the occurrence of spontaneous pneumothorax, (2) pneumatoceles, (3) combinations of diffuse emphysema, rapidly changing parenchymal signs and loculated empyema Films taken in the erect position are especially important to facilitate early recognition of a pyopneumothorax[6]

The diagnosis is not certain until the hemolytic *Staphylococcus aureus* has been identified in cultures obtained from pleural fluid, blood, or the lung itself in the living patient[3] The presence of pathogenic staphylococci in nose and throat secretions does not positively establish the diagnosis, for such organisms have been found in the nasopharynx of more than 60 per cent of normal infants only 7 days old[22] and in about 85 per cent of nose and throat cultures on routine pediatric admission[2]

The mortality rate of staphylococcal pneumonia before the advent of chemotherapy and antibiotics was as high as 100 per cent,[6 25] and it was not greatly reduced after the adoption of the sulfonamides with or without antitoxin or bacteriophage[3 6 24] The mortality rate for infants below the age of 4 months was particularly high as compared with that of older infants and children[10]

After the advent of penicillin this mortality rate was considerably reduced Eventually however, and more and more frequently, strains of staphylococci were encountered that were quite resistant to penicillin in the usual dosages These strains were at first sensitive to streptomycin[20] but later developed increasing resistance to a number of antibiotics Aureomycin and Terramycin in combination with penicillin were sometimes recommended[8 1]

From the Departments of Surgery and Pediatrics Yale University School of Medicine New Haven Conn

Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City New Jersey April 24 to 26 1955

The importance of closed thoracotomy drainage in treatment of an associated empyema, and particularly of pyopneumothorax, has been stressed by Forbes[9] and by Blumenthal and Neuhof[3] More recently there has been a tendency to avoid surgical drainage and to attempt sterilization of the empyema cavity with systemic and intrapleural antibiotics Even so, the patients have not been spared the sudden development, even relatively late in the disease, of a tension pneumothorax Moreover, one author, Klassen,[18] found it necessary to advise decortication in 10 cases so treated In his series the average time from onset of symptoms to decortication operation was 30 days

Our experience tends to confirm previous opinions as to the importance of early surgical drainage Staphylococcal pneumonia and empyema still pose a very serious threat to numbers of infants, and further clarification of the problems in this disease is needed

TABLE I CLINICAL FINDINGS ON ADMISSION IN THE TEN CASES FIRST ADMITTED TO NEW HAVEN HOSPITAL

FINDING	NUMBER OF CASES
Irritability	4
Lethargy	2
Grunting respirations	5
Cyanosis	3
Upper respiratory infection	5
Inflamed eardrum	1
Chest findings	
Diminished breath sounds	5
Dullness	5
Râles	5
Friction rub	1
Tubular breath sounds	1
Pustular skin rash	1
Umbilical granuloma	1
Soft tissue abscesses	1
Abdominal distention	5
X ray findings	
Parenchymal infiltration	8
Pleural effusion	6
Hydropneumothorax	1

There were admitted on the pediatric and surgical services at the New Haven Hospital over the past eleven years (from March, 1944, to March, 1955) 11 infants in whom the diagnosis of staphylococcal pneumonia has been definitely proved Some other cases were tentatively diagnosed, but lacked bacteriological verification from blood or pleural fluid The 11 infants ranged from 1½ to 16 weeks in age with an average age of 6 7 weeks Admission to the hospital varied from one to seven days after the onset of symptoms (One patient had been admitted to another hospital during the acute phase and was transferred to New Haven after a month of treatment)

The clinical picture at the time of admission was sometimes deceptively mild The average temperature elevation was only 38 5° C (101 3° F) Other findings at this time are listed in Table I Some infants were irritable while others were lethargic Labored respirations were noted in one-half of the patients but only 3 of the 10 acutely ill patients were actually cyanotic The common findings on physical examination of the chest were diminution of breath sounds, percussion dullness, and râles, but these were not noted in all patients Abdominal distention was evident in at least one-half of the cases Radiographically there was evidence of parenchymal infiltration on admission in 8 of 10 patients in an acute condition pleural effusion in 6, and hydropneumothorax in 1

Positive cultures for hemolytic *Staphylococcus aureus* were obtained from the pleural fluid of the 9 patients who developed an effusion The remaining 2 patients had positive blood cultures of the same organism

Drug-sensitivity studies were carried out in 7 cases, in only 3 of these were the organisms sensitive to penicillin From results of sensitivity tests as recorded in Table II it appears that erythromycin and Chloromycetin were the drugs to which the staphylococci were most consistently sensitive

TABLE II. DRUG SENSITIVITY OF ORGANISMS*

CASE NO	BACITRACIN	PENICILLIN	STREPTOMYCIN	ERYTHROMYCIN	TETRACYCLINES†	CHLOROMYCETIN
1 2, and 4	(Sensitivity tests not performed in these cases)					
3	–	Sensitive to 4 U/c c.	–	–	Sensitive to 0 25 mg /c c.	–
5	–	++	–	++	++	–
6	–	0	0	+	+	++
7	++	0	+	+++	+	+
8	–	0	0	+++	++	++
9	0	0	0	+++	0	+++
10	–	++	++++	++++	++++	++++
11	–	0	++	++	++	++

*Number of plus signs indicates degree of sensitivity Lack of sensitivity indicated by zero Instances where the test was not performed are indicated by a dash.

†(Terramycin, Aureomycin, and Achromycin)

In Case 3 sensitivity tests were performed by the test tube method. In the remaining instances the disc method was used, and the size of the zone of inhibition around the disc is denoted by the number of plus signs

Thoracentesis was performed in all except 2 infants In 1 of these a marked tension pneumothorax developed before a thoracentesis had been performed Closed suction drainage with catheter was immediately instituted as an emergency measure In the 9 cases where thoracenteses were performed they ranged in number from one to twenty-three with an average of four per infant

Closed suction drainage was employed in 8 of the 11 cases It was instituted at any time from the first hospital day to the thirty-second. In 4 instances it was required in the treatment of pneumothorax. 3 of these with tension. In 4 other cases, it was done primarily to facilitate drainage of the exudate In some cases the tube was of polyethylene inserted through a wide-bore needle In 1 case, this type of small-bore tubing was found inadequate to control a tension pneumothorax and a larger catheter of rubber had to be substituted Resection of a short segment of rib under local anesthesia to permit the insertion of a No 14 or No 16 F rubber catheter has been well tolerated even in the very ill infant

Streptokinase streptodornase was used in 1 case in an attempt to facilitate liquefaction of exudate after placement of a drainage tube We have been hesitant to use it in the usual fashion in these cases lest it favor reopening of a bronchopleural fistula occluded by exudate or develop a new one by liquefaction of a peripheral abscess

Three cases may be used by way of illustration of problems encountered in the course of treatment of this disease

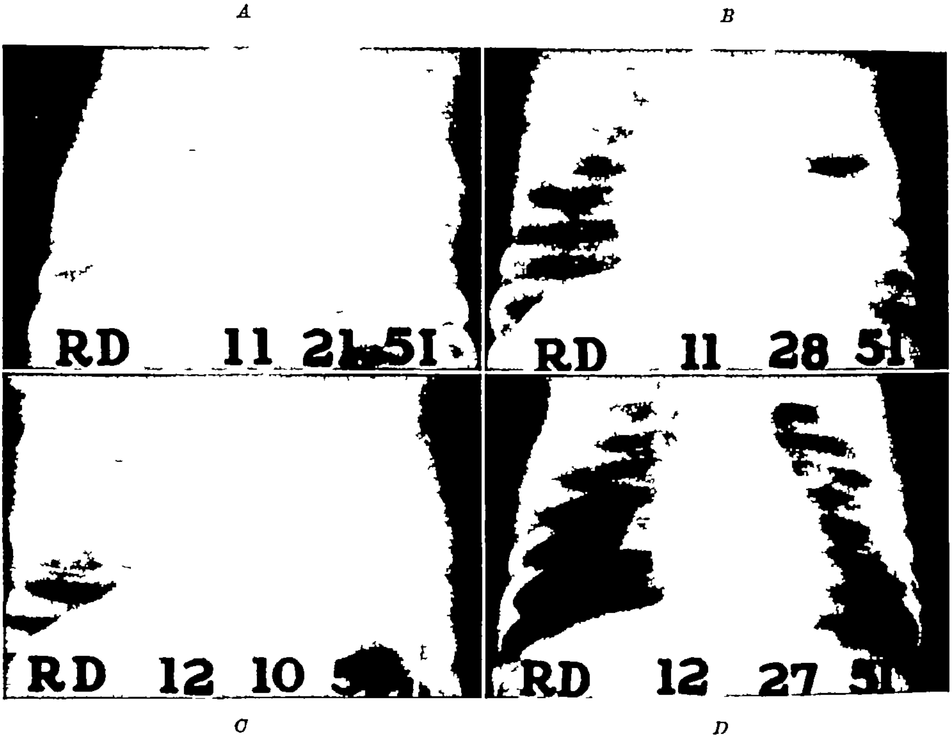

Fig 1 —R. D *A* Left upper lobe pneumonia *B* Pyopneumothorax secondary to broncho pleural fistula *C* Clearing on closed suction drainage *D* Clearing almost complete.

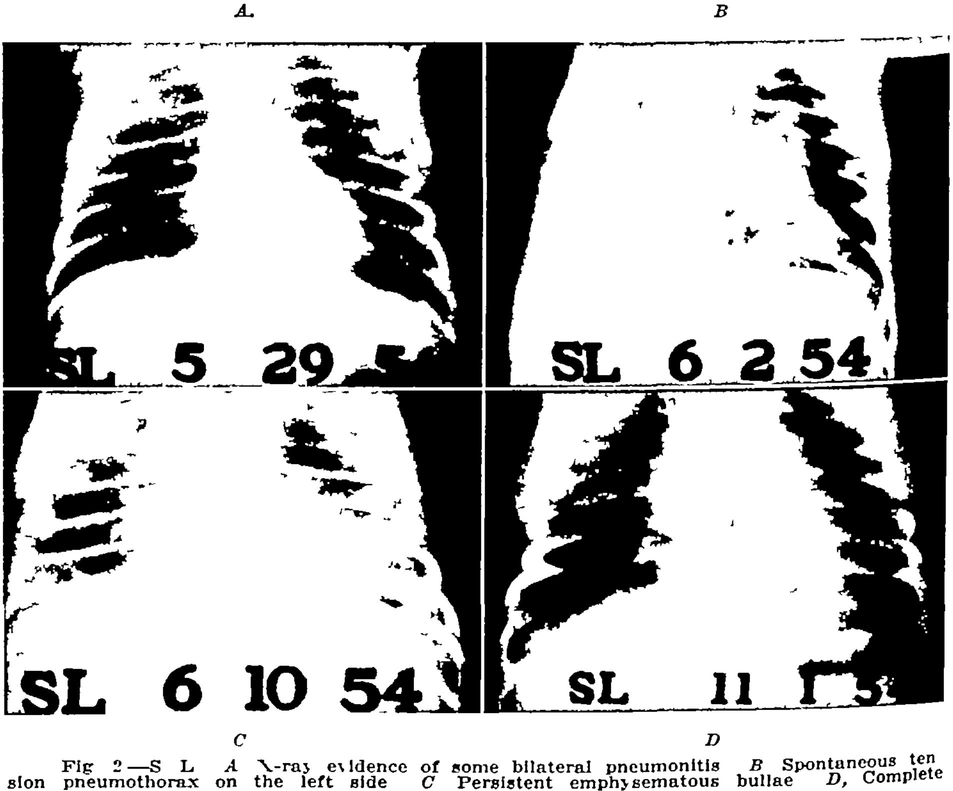

Fig 2 —S L *A* X-ray evidence of some bilateral pneumonitis *B* Spontaneous tension pneumothorax on the left side *C* Persistent emphysematous bullae *D*, Complete clearing

CASE REPORTS

CASE 4.—R D, a 16 week old male infant, was admitted after four days of upper respiratory symptoms with a fever and labored respirations On admission the temperature was 40° C (104° F) There were dullness and diminished breath sounds and occasional rales over the left upper lobe and marked abdominal distention The admission chest film (Nov 21, 1951) showed evidence of pneumonia of the left upper lobe with slight involvement of the left lower lobe (Fig 1) He was treated with thoracenteses and systemic antibiotics for the first ten days Thereafter, because a bronchopleural fistula resulted in pyopneumothorax a Polyvinyl tube was inserted and closed suction drainage was used for thirteen days Terramycin was also instilled daily through the Polyvinyl tube Chest roentgenograms taken five weeks after admission (Dec 27, 1951) showed almost complete clearing

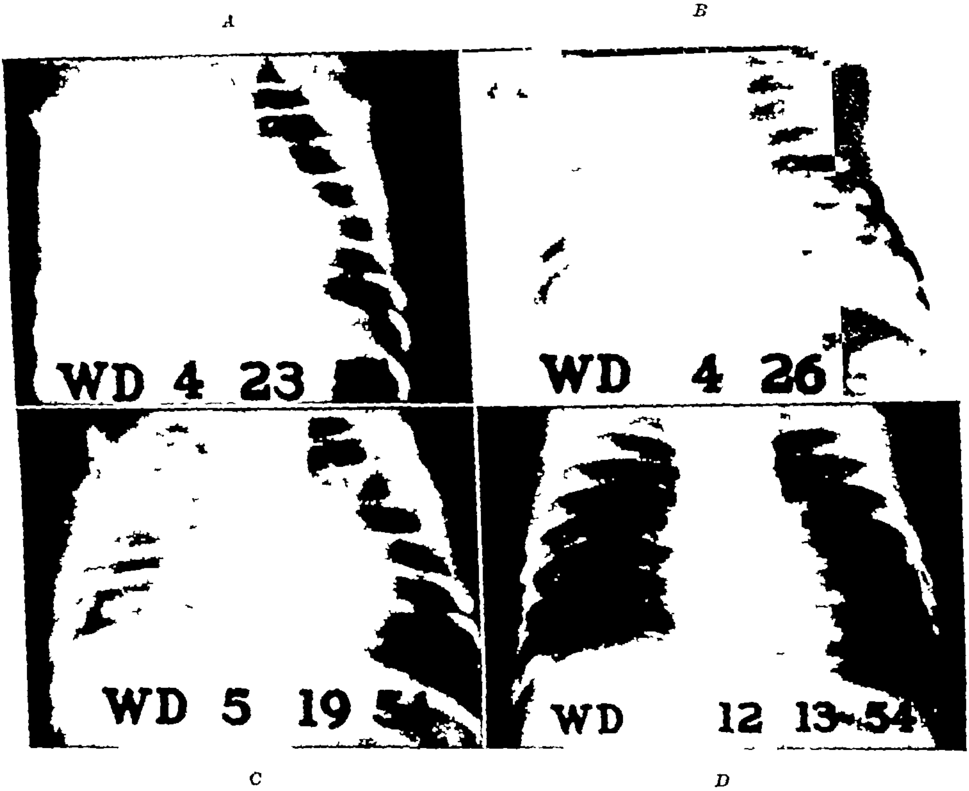

Fig 3—W D A Pneumonia and pleural effusion on right side B Further loculation of empyema. C Rib resection and closed suction drainage begun D Complete clearing seven months later

CASE 5—S L, a 1½ week old female infant, was admitted after three days of gastrointestinal upset with vomiting Examination then revealed a temperature of 39° C (102° F) grunting respirations moist rales over both the right and left lower lobes, abdominal distention and abscesses of the arm and leg The admission x ray (May 29, 1954) was read as "bilateral pneumonitis" (Fig 2) On the fourth hospital day the infant developed a spontaneous *tension* pneumothorax on the left side (June 2, 1954) This was treated with polyethylene catheter suction drainage The catheter was removed after five days Emphysematous bullae persisted as shown in a film taken eight days later (June 10 1954) A final film taken five months later (Nov 1 1954) showed complete clearing

CASE 6—W D, a 2 week old male infant, was admitted after one day of fever and irritability Examination revealed a temperature of 39.4° C (103° F), evidence of a mild upper respiratory infection, abdominal distention, and scattered pustular lesions over the posterior aspect of both thighs The chest appeared clear Four days later signs of pneumonia appeared and a chest film obtained then (April 23, 1954) revealed pneumonia and a pleural effusion on the right side (Fig 3) He was treated with thoracenteses and systemic antibiotics, including penicillin, streptomycin, and Achromycin, for a month On the thirty second hospital day, closed thoracotomy suction drainage via a No 12 F rubber catheter was instituted, as seen in the x ray labeled (May 19, 1954), and soon thereafter antibiotic therapy was changed, because the organism that had been sensitive to Achromycin was now more sensitive to Chloromycetin Irrigations of bacitracin solution were also used Despite its local use in doses which were not excessive when calculated on a comparative weight basis with reference to adult doses, the patient developed albuminuria after four days This was a reaction observed by us in 3 other infants under similar circumstances, and we believe considerable caution must be exercised in its use in this age group In this case, closed suction was discontinued after thirteen days and the tube was removed after two more weeks The extent of eventual clearing is seen in a film taken seven months later (Dec 13, 1954)

RESULTS

The mortality rate in this series was zero The average length of hospitalization in the 10 cases admitted directly to our hospital was thirty-two days, with a range of six to fifty-eight days Most of the patients were kept on antibiotics for an additional one to two weeks after discharge from the hospital despite the fact that they appeared to be clinically well None of the patients has required a subsequent decortication for treatment of a fibrothorax, although 1 patient, still under observation, may possibly require such an operation

DISCUSSION

From this relatively small series of bacteriologically proved cases, all treated in the antibiotic "era" several features seem to be of particular importance in management Antibiotics alone or in combination, even though based on adequate sensitivity tests, do not result in cure in many cases Supplementary surgical drainage by a closed suction system has been curative in patients who have been submitted previously for days or weeks to multiple thoracenteses but with failure to show much clinical improvement until adequate catheter drainage was obtained Even after surgical drainage, antibiotic therapy should be continued for several weeks

Tension pneumothorax is a complication which can occur early or late even though the patient is responding well to antibiotic therapy, and a small bore polyethylene catheter may be inadequate to cope with it completely Appropriate equipment must be on hand in the patient's room to meet this possible emergency of a tension pneumothorax at all times after the infant is admitted to the hospital

A few cases with residual radiographic densities typical of exudate and thickened pleura have in a period of one to two months shown remarkable improvement without the necessity of a decortication The residual pleural densities and emphysematous changes in this early age group show an exceptional tendency for spontaneous resolution, and we advise against unnecessarily early decortication or corrective pulmonary surgery

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Discussion

DR JOHN M SNYDER, Bethlehem, Pa —We have had a veritable epidemic in our hospital, and I would like to present seven cases all of which occurred between Dec 1, 1954, and the middle of Feb, 1955 In this group the ages were 5 weeks in two patients 7 weeks in one 4 months in one 20 and 22 months in two, and finally we had a 10 year-old boy who fitted into the same picture I would like to compliment Dr Bloomer and his group on their remarkable success in their series, because our experience was considerably sadder Our first three cases were fatal. All these patients had bilateral infection, one with bilateral empyema. The white cell counts on admission were between 25,000 and 35,000, and we were unable to find the organisms by nose and throat cultures The organisms were confirmed by culture usually from thoracentesis or as in two of the first three cases, by post mortem.

This seems to be a highly infectious process because the fifth patient in the series had been in the hospital for some time when he suddenly developed this disorder

The pathologic findings to summarize were as follows Besides the pneumonia in all of them three of the patients developed pneumatoceles, six had empyema, and the quantity of fluid which accumulated made it an emergency problem Three had bronchopleural fistulas with tension pneumothorax Of the three patients who *died* we were able to get permission for post mortem examination on the second and third Several of the infants were brought in for investigation of what was anticipated to be a gastrointestinal disorder, but the pulmonary difficulties became evident shortly

The first patient was critically ill for five days with a pneumonia on the right side showing a pneumatocele On the sixth day of admission, the left chest had been checked by several individuals on that morning, and was clear, but about noon a left tension pneumothorax suddenly developed and despite aspiration the child died about two hours later The next child had bilateral bronchopneumonia involving the right lower and middle lobes and the left lower lobe There was severe pulmonary infection bilaterally, and bilateral empyema The child died within thirty six hours after admission, and post mortem examination showed a bilateral confluent bronchopneumonia with multiple abscess formation, with bilateral empyema and turbid fluid in the pericardium These pathologic findings will be reported in detail by our pathologist in the near future in our hospital bulletin The pathogenesis of the pneumatoceles seemed to be an ulcerative bronchitis which went on to perforation and localized peribronchial abscess, and air escape by ball valve action to form the parenchymal air spaces The third child showed a small amount of fluid on the right side by x ray, but died suddenly within two or three hours following x ray, while being prepared for thoracentesis At post mortem, almost 900 c c of empyema fluid were recovered from the right chest, which shows the rapidity of formation of and excess quantity of fluid which one has to anticipate in these cases

In the remaining cases, the organism was generally sensitive only to Chloromycetin, or briefly to erythromycin Cases 4 and 6 required emergency closed catheter drainage of the chest for tension pneumothorax with empyema Case 5 developed large confluent pneumatoceles which eventually resolved without drainage, on Chloromycetin therapy The last case required both thoracotomy drainage of the empyema and secondary drainage of the infected pneumatocele before recovering

DR GABRIEL SELEY, New York, N Y—I wish to thank the authors of this paper for again bringing to our attention this important subject This disease is thought of as suppurative bronchopneumonia, as was emphasized by Dr Neuhof years ago The microorganisms responsible are staphylococci or streptococci or even pneumococci Operations now are limited to pleural complications, whereas at one time it was necessary to operate for lung abscess These pleural complications are very frequent because of the nature of the disease There is a necrotizing process and the lesions are peripherally located in many instances Once the pleural complications are taken care of, the prognosis depends on the underlying pulmonary disease We have used closed drainage very freely without suction with a good sized red rubber catheter with multiple holes in the catheter The reason for the use of a red rubber catheter is that it can be visualized on the x ray

If operation is decided upon it can be done under local anesthesia in the infant and, as a matter of fact, even under oxygen therapy We have not employed suction with this type of closed drainage, and the only patients who have succumbed with this method of treatment were those in whom resection had been performed The resection, if done at all, should be a limited one, combined with decortication, but any operation should be avoided in addition to closed drainage, if possible We do not use aspiration at all, with or without the use of antibiotics, because we feel that the relief is minimal and transient, it is painful for the infant, and may actually injure the lung, and the tendency toward mediastinal fixation is disturbed by multiple aspirations We have not found it necessary to employ enzymes and, as a matter of fact, we advise against it

DR G M BROWNRIGG, St John's, Newfoundland—During the past five months we have encountered sixteen cases of staphylococcic pneumonia in children In all cases that came to autopsy or to operation, the organism was identified as a penicillin resistant staphylococcus Fourteen patients ranged in age from 4 to 21 months, one was 6 years of age, and one was a 15 year old boy There were six deaths All came to autopsy and on post mortem examination all were found to have in addition to the pneumonic process single or multiple lung abscesses with bronchopleural fistulas

In eleven of the sixteen cases the diagnosis was established and adequate treatment instituted. All eleven patients showed radiologic evidence of abscess formation which developed rapidly Seven of the eleven patients developed bronchopleural fistula with empyema and tension pneumothorax. Drainage was instituted promptly in seven of them and six recovered one died and came to autopsy Four were treated with antibiotics alone and remain clinically well. All four to date however show residual translucent areas on x ray examination The over all mortality was 31 per cent In eleven cases in which diagnosis was established early and vigorous treatment instituted there was one death.

It is interesting to note in our series that in the patients who developed fistulas and in whom drainage was done subsequent x rays did not show persistent translucent areas In those cases which did not rupture translucent areas still remain in the x rays They have not been followed sufficiently long to know what is going to become of them. I would like to report that one patient in whom the organism was sensitive to erythromycin and Chloromycetin on admission had cultures taken from the draining sinus after recovery just prior to discharge which showed that the organisms were no longer sensitive to these drugs

From our experience we would like to support Dr Bloomer s plea for early recognition of these cases for careful observation to detect the onset of empyema and more particularly tension pneumothorax, and for prompt and efficient drainage when these complications occur

DR E D GAGNON Montreal Quebec—We have had occasion over the past six years to treat forty seven infants suffering from this condition. Seventy per cent of these patients had empyema and bronchopleural fistulas and all were treated with catheter suction plus antibiotic therapy There were two deaths in this series and the two deaths were attributed to septicemia one with meningitis and the other with brain abscess It was very interesting to us to note the frequency of loculation of the empyemas in these infants and we found that in 50 per cent of the cases we had to insert a second catheter after a few days one anteriorly and one posteriorly With this mode of therapy the fistulas healed in all cases except one that required decortication and closure of the fistula

It was also interesting to see five cases with multiple lung abscesses underlying the empyema These multiple lung abscesses healed without surgery except for drainage of the empyema I give this only as added proof that catheter and suction drainage is successful in treatment of this condition but I would strongly advise two catheters instead of one at the initial drainage one anterior and one posteriorly

DR DONALD MILLER Burlington Vt—In the past four and a half years we have had experience with approximately 25 cases of empyema in infants and children and the purpose of these comments is to point out the success we have had by using closed thoracotomy drainage and enzymatic debridement

Not all of these cases were proved to have staphylococcus infection but in those cases where bacteriologic proof was lacking the clinical course was such as to justify this as a presumptive diagnosis Treatment consisted of closed thoracotomy drainage done in most instances as soon as the presence of empyema was established Enzymatic debridement with Varidase was used promptly and repeatedly in every case regardless of whether or not pneumothorax was present Penicillin and streptomycin were instilled through the tube on alternate days No difficulty was encountered in keeping the tube open Febrile reactions to Varidase occurred but none were sufficiently severe to cause alarm or deter subsequent use of Varidase if it was indicated

There were no deaths Every patient now has what appears to be a normal chest x ray except for 2 who still display small pneumatoceles which are slowly disappearing In no case was surgery required

DR RICHARD H MEADE Grand Rapids Mich—I should like to emphasize the fact that serious hemoptysis may occur in cases other than those of carcinoma and tuberculosis Some fifteen years ago in Philadelphia a young woman entered the Philadelphia General Hospital with massive hemorrhage Some years before she was thought to have apical tuberculosis and was treated accordingly In the case of this patient, the x rays showed a very small apical scar in the right lung, nothing else was found The hemorrhage was so profuse that pneumothorax was induced and the lung was completely collapsed The hemorrhage continued She was given blood transfusions daily It was assumed that she must be bleeding from the site at which she had had tuberculosis

Finally, in desperation, it was decided that something must be done surgically She was bronchoscoped with great trepidation by our bronchoscopist and it was seen that the blood was coming from the right bronchus It was not quite certain whether it was from the upper or lower lobe At the operation the lung appeared completely normal except for the apical scar A pneumonectomy was done, and the lung was studied closely and no evidence of disease could be found except for one very small area in the lower lobe, and microscopic examination revealed evidence of bronchiectasis The patient recovered and had no further bleeding

I think this was a very unusual case, which corroborates the essayist's statement in making one realize that sometimes hemoptysis cannot be explained before operative procedure is carried out

DR LEO ELOESSER, San Francisco, Calif —In the second slide Dr Bloomer showed what looked like emphysematous bullae in the lung I have seen similar annular shadows in metastatic staphylococcic pneumonia following staphylococcic bacteremia and osteomyelitis in children Also, they seem to be not uncommon in pulmonary tuberculosis treated with streptomycin and Isoniazid They do not persist, but disappear after a few weeks or months I wonder whether Dr Bloomer could offer an explanation of these annular shadows and the phenomena they represent

DR LEWIS H BOSHER, Richmond, Va —I have one case to show which is rather interesting from the standpoint of pneumatocele The patient was a 2 month old Negro female child, who was admitted to the hospital with fever, septicemia, and metastatic abscesses of the lower leg

There were large round densities in both upper lung fields The child was very sick at this point and was treated with penicillin and streptomycin About two weeks later the density on the left side had been replaced by a very large tension cyst The density on the right persisted Treatment with antibiotics was continued and the child gradually improved Approximately two months later the tension cyst on the left side still persisted, with clearing on the right The child was discharged from the hospital since she had no respiratory embarrassment, and over the period of the next two months this cyst completely disappeared We have a follow up about two and a half years later and we believe the films are essentially normal

DR GUSTAF E LINDSKOG (Closing) —I should like to thank the various discussants for their contributions to this presentation, and also admit the fact that many of these series are much larger than our own With respect to the question of getting positive cultures, the answer is very simple We did not include in this presentation any case in which positive cultures were not obtainable So we did not have any special trick There were some cases in which positive cultures were not obtained, but these are not included

We would like to offer in response to Dr Eloesser's question this tentative explanation for the pneumatocele, there is a valving tension effect produced by obstruction from the bronchial edema and exudates, and at the same time an interference with collateral ventilation mechanisms in the peripheral portion of the pneumonitic lung These two factors, bronchial valving obstruction, and interference with collateral ventilation, set the stage for this very commonly associated phenomenon

We might summarize with re emphasis of the fact that pneumatocele and emphysema are common complications in this disease They are usually transient and quite reversible phenomena, but not always Spontaneous pneumothorax can occur at any time and when the patient is clinically doing very well, even late in convalescence

Sound principles of surgical drainage of the empyema, as emphasized in the past by senior members of this Association, are not yet outmoded They are still very important in the management of the staphylococcal empyema

MANAGEMENT OF MASSIVE HEMOPTYSIS, NOT DUE TO PULMONARY TUBERCULOSIS OR NEOPLASM

J. L. Ehrenhaft, M.D. and Rodman E. Taber, M.D. (by invitation)
Iowa City, Iowa

HEMOPTYSIS is a symptom frequently encountered in diseases of the cardiac and pulmonary systems. The bleeding may be slight in amount and only stain the sputum or expectorated purulent material. Sudden, severe hemoptysis is probably one of the most alarming things which may happen to a patient and occasionally during a massive hemorrhage death may result. This paper will be concerned only with the type of patients who have severe pulmonary bleeding which if continued would constitute an immediate threat to life.

In a group of patients under our observation, hemoptysis frequently amounted to more than 500 c.c. during one episode. In some of the patients, there was no previous history of pulmonary disease and the bleeding was the initial symptom. Death may result either by drowning in aspirated blood or actually by exsanguination. We encountered 12 such patients during the last five years on the Surgical Service of the State University of Iowa Hospitals. Thoracotomy and pulmonary resections were performed to stop the bleeding from the pulmonary tract. Active pulmonary tuberculosis or pulmonary neoplasms were not etiological factors in this group. Frequently the erroneous diagnosis of a pulmonary neoplasm had been made prior to surgical exploration in spite of the knowledge that hemoptysis in patients with a bronchogenic carcinoma is usually a late symptom. We observed severe hemoptysis only in patients with adenomas of the bronchus. These patients usually bled over a longer period of time and had other typical findings. We also did not include patients with generalized disease which might cause bleeding, neither did we include patients with primary cardiovascular diseases of congenital or acquired nature. Rather extensive reviews have been published in the recent literature quoting the incidence of hemoptysis as it has been observed in different disease entities.[1, 3, 6, 7, 8] The most frequent causes for hemoptysis are quoted to be bronchiectasis, pulmonary abscesses and pulmonary tuberculosis. Acquired cardiac disease, as for instance mitral stenosis, may be the cause of hemoptysis of moderate degree, while congenital cardiovascular lesions very rarely produce pulmonary bleeding.

All patients were considered to be in good health prior to the onset of the severe hemoptysis with the exception of one, Case 5. This patient gave a history of intermittent severe pulmonary bleeding over the past four years and

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Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City, New Jersey, April 24 to 26, 1955.

TABLE I

	CASE	AGE	SEX	PREVIOUS HEMOPTYSIS	BRONCHOSCOPIC LOCALIZATION	SIDE LOCATED BY PATIENT	SURGERY PERFORMED	PATHOLOGIC DIAGNOSIS
1	E S 49 13584	54	M	+	Left upper lobe	-	Left upper lobectomy	Stenosis of bronchus, second order, cause undetermined, upper lobe, left lung Extravasation of blood in bronchioles and alveoli
2	F N 49 14345	60	F	-	Left lower lobe	-	Left lower lobectomy	Broncholithiasis, left lower lobe
3	A S 49 15375	62	F	-	Left lung	-	Pneumonectomy, left	Broncholithiasis, left lung, chronic inflammation and scarring *of bronchi, especially* severe in bronchus to left lower lobe with enlargement and sclerosis of bronchial arteries *Pulmonary hemorrhage*, severe, left lung
4	D W 50 10890	38	F	+	Right lower lobe	-	Right lower lobectomy	Broncholithiasis and calcific bronchial nodes
5	G T 40 4253	62	M	+	Lingula and anterior pectoral segment, left upper lobe	+	Pneumonectomy, left	Bronchiectasis, mild, lingula and left lower lobe
6	W N 51 1945	69	M	-	Right lower lobe	+	Right lower lobectomy	Calcific lymph node encroaching *upon* bronchus at bifurcation of lower lobe bronchus, right lung Intrabronchial hemorrhage due *to erosion of* bronchus, lower lobe, right lung
7	W B 52 2335	44	M	+	Not localized	-	Resection of calcific node, left main stem bronchus	Calcific peribronchial node, left main stem bronchus
8	L W 52 11938	67	M	-	Lingula	+	Lingulectomy	Broncholithiasis, chronic *peribronchial* pneumonitis and squamous metaplasia of bronchial mucosa, lingular bronchus
9	C T 53 13355	67	M	-	Right upper lobe	+	Right upper lobectomy	Hemorrhage in right upper lobe, cause undetermined
10	B H 54 2346	40	M	-	Left upper lobe	-	Left upper lobectomy	Chronic pneumonitis and hemorrhage in parenchyma, left upper lobe, cause undetermined
11	N A 54 10122	51	F	-	Lingula	+	Lingulectomy and resection posterior basilar segment, left lower lobe	Bronchiectasis, mild
12	J R 54 10028	55	M	+	Right upper lobe	+	Right upper lobectomy	Pulmonary hemorrhage, source and etiology undertermined

was known to have some localized bronchiectasis and pulmonary emphysema Four additional patients in this group had experienced at least one previous episode of pulmonary bleeding These were of varying degrees of severity As has been mentioned by other authors [8] the degree of hemoptysis bears no relationship to the gravity of the underlying pulmonary disease In each instance the underlying primary cause itself was not a threat to life except for the production of the massive bleeding This can be illustrated by the pathologic findings in this group of patients Bronchiectasis of mild degree was demonstrated in 2 patients broncholithiasis or calcified peribronchial lymph nodes in 6 other patients No specific cause for the massive bleeding could be found in the remaining 4 cases (Table I)

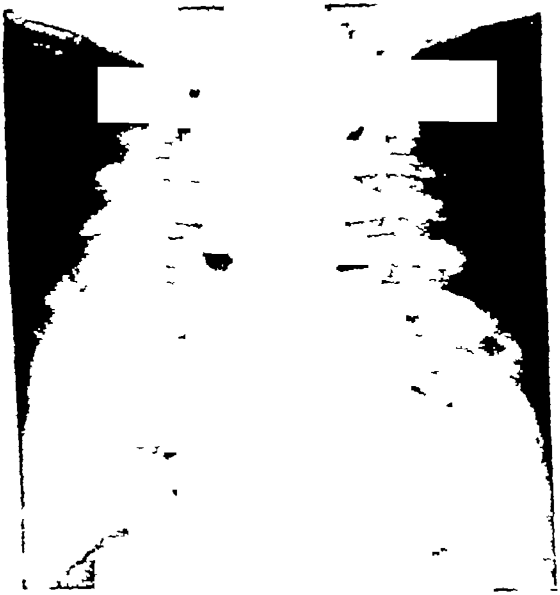
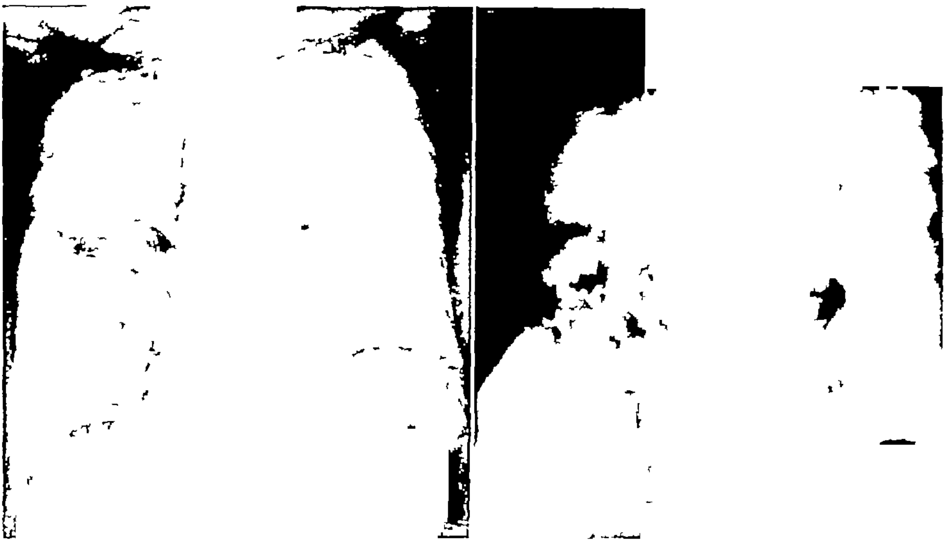


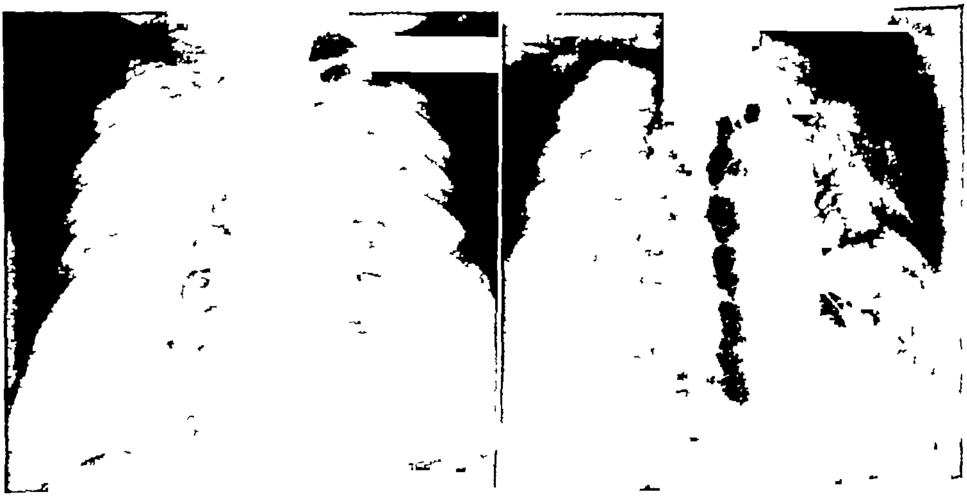
Fig 1 —Case 12 Chest roentgenogram showing aspiration pneumonitis in right lower lung field Bronchoscopy localized the source of bleeding in the right upper lobe

The main preoperative problem is the exact localization of the site of hemorrhage Occasionally patients will be able to state from which lung they believe the bleeding arises This was the case in one-half of our patients A vague sensation or discomfort or pain may be present Splinting of the involved side may be noted Physical findings may be helpful but are also misleading due to the involvement of other portions of the lungs by aspirated blood. Roentgenograms of the chest very frequently will help in localization as to which lung is the source of the hemorrhage but may be misleading in the localization by lobes or pulmonary segments (Fig 1) The visualization of calcific peribronchial nodes in the chest roentgenogram appeared to us to be very significant [16] Planograms and roentgenograms in different positions of rotation are helpful in the demonstration of the anatomical relationship of the calcific masses or peribronchial nodes to the bronchial tree (Fig 2) Bronchographs may at times be valuable but usually is of limited usefulness



A *B*

Fig 2 —*A* Chest roentgenogram and *B* planogram demonstrating the presence of calcified peribronchial lymph nodes and broncholiths The latter were not plainly visualized on the posteroanterior chest roentgenogram



A *B*

Fig 3 —Case 1 *A*, Chest roentgenogram demonstrating some infiltrate in left mid lung field *B* Bronchogram demonstrating blockage of bronchus leading to the anterior pectoral segment which was the site of hemorrhage.

during the active phase of bleeding[5] (Fig 3) It is not only difficult but also may be misleading due to the blockage of different portions of the tracheobronchial tree by aspirated blood Demonstration of bronchiectatic changes by Lipiodol instillation during quiescent periods is of the greatest importance[2, 6, 9] (Fig 4)

In our opinion, the most valuable procedure which must be carried out in all patients with hemoptysis is bronchoscopy[1, 2, 5, 9] This investigation

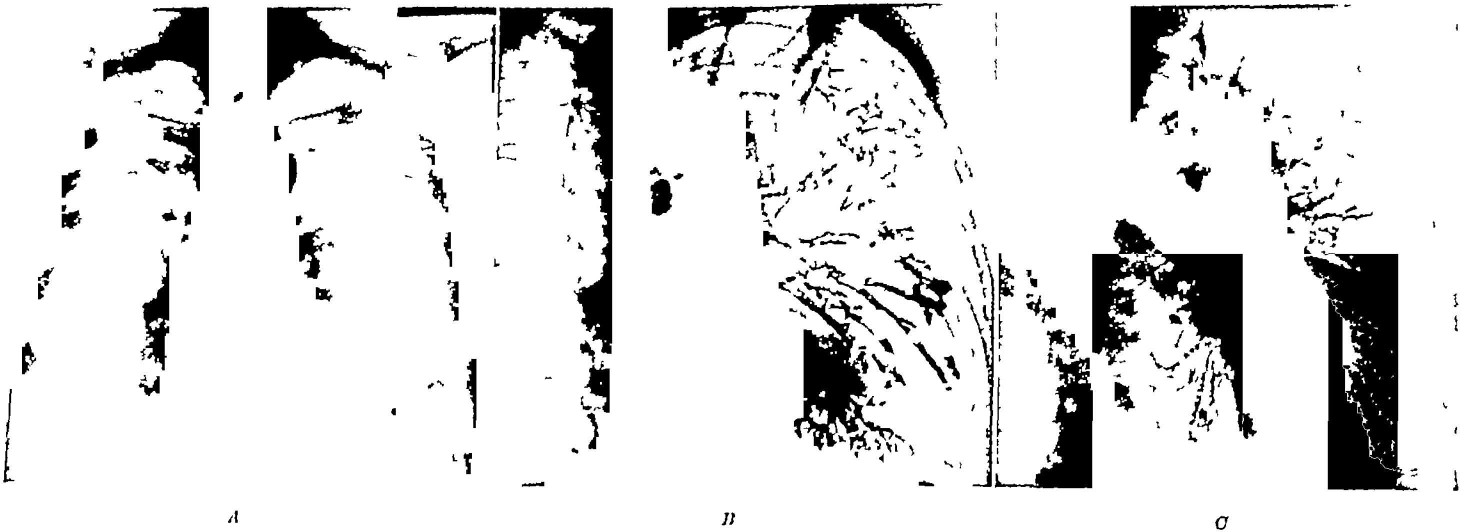


Fig. 1—Case 5. A. Normal appearing chest roentgenogram. B. Bronchogram prior to episode of massive hemoptysis demonstrating bronchiectasis in the lingula and anterior pectoral segment of left upper lobe. C. Bronchogram carried out during episode of hemoptysis demonstrating failure of bronchiectatic segments to fill.

must be done during the time of active bleeding. The source of bleeding may not be visualized directly but at least it will be possible to determine the lobar or occasionally the segmental bronchus from which the blood is coming. This procedure must be done with the greatest care. Removal by suction of all endobronchial clots is essential. The visualization of fresh blood coming from a bronchial orifice under these circumstances can then be taken as certain and the proper localization of the source of hemorrhage. Facilities for immediate thoracotomy should be available at that time. Reactivation of severe bleeding has occurred in some of our patients necessitating emergency pulmonary resection as a lifesaving procedure. A delay in carrying out bronchoscopy until bleeding has stopped may not be possible and also is undesirable. The opportunity to localize the site of hemorrhage may have passed by that time.

We believe an episode of massive hemoptysis is a definite indication for exploratory thoracotomy. As soon as all possible and indicated diagnostic procedures have been completed in an attempt to localize the site of hemorrhage, surgical exploration should be performed.[1, 3, 6, 9, 10] Lobar and, if possible, segmental localization is certainly desirable but exploration should not be withheld if the side from which the bleeding arises has been demonstrated. Prolonged observation in hopes that a massive hemoptysis may stop usually leads to further difficulties. Frequently the patients may show some reduction of the amount of hemorrhage only to resume severe bleeding at unexpected moments. Invariably, the patients develop extensive aspiration pneumonitis, atelectasis, and later pulmonary infections. This may happen in spite of all efforts to prevent aspiration into the opposite bronchial tree and even with the best possible measures to protect the noninvolved pulmonary tissue. Reduction of functioning lung tissue further decreases the patient's chances for survival during, or recovery after, surgical intervention.

Protection of the contralateral bronchial tree from aspiration of blood is most important. Positioning the patient to promote adequate drainage may be of value. Mild sedation to promote rest but not enough to reduce the cough reflex is advisable. Other forms of conservative treatment, in an attempt to reduce the pulmonary bleeding, are in our opinion not indicated in this group of patients. Temporary or permanent collapse procedures of one type or another may be of value in patients with pulmonary tuberculosis in whom immediate resection is not advisable. In the latter situation, one is usually dealing with pulmonary arterial bleeding arising in parenchymal cavitary lesions while in the group of patients under discussion little benefit can be expected by collapse therapy since the source of bleeding is of bronchial artery origin.[7]

The operative management of those patients requires extremely close co-operation between the anesthetist and surgeon. Good anesthetic management during the surgical procedure is absolutely essential. Occasionally patients have had to be transported to the operating room with a bronchoscope lying within the trachea to assure an open airway. Endotracheal intubation under topical anesthesia should be rapidly performed in this situation, preferably while the patient is still awake. Occasionally, intubation of the contralateral main bronchus is indicated to assure prevention of aspiration of blood into the noninvolved lung The head of the operating table should always be lowered to promote adequate drainage and to facilitate tracheal toilet Adequate restoration of blood volume by blood transfusions, started prior to operation, must be continued during the surgical procedure At the time of exploration, evaluation of the pulmonary lesion may be difficult and confusing Aspirated blood may produce areas of atelectasis and obstructive emphysema which involve pulmonary segments or entire lobes Exploration of

Fig 5—Case 7 A Chest roentgenogram demonstrating calcific peribronchial lymph node in area of left main bronchus. B Bronchograms demonstrating calcific peribronchial lymph node protruding into lumen of left main stem bronchus.

(Fig 5 C on following page)

the bronchial tree may demonstrate the calcific peribronchial nodes which are so frequently the cause for this type of bleeding[10] To make a decision as to the extent of resection necessary by exploration alone is often very difficult The preoperative bronchoscopic indication of the site of bleeding will give additional assurance to the surgeon and it will also help in the decision as to the extent of resection to be carried out Lung parenchyma showing atelectasis or obstructive emphysema due to aspiration should never be resected on the basis of these findings alone One should always be guided by the position and relation to bronchi of the calcific peribronchial nodes and the preoperative localization of the bleeding In one of the patients, it was possible to enucleate a calcific peribronchial node which was embedded within the membranous portion of the left main stem bronchus without performing pulmonary resection (Fig 5)[4] In patients in whom areas of bronchiectasis have been demonstrated, resection of only the involved lobes or segments should be performed In the group of patients in whom no cause for the bleeding could be found at the time of thoracotomy, one has to rely entirely upon the preoperative localization of the site of bleeding Occasionally more extensive removal of pulmonary tissue than was anticipated may be required Periarterial fibrosis, scarring, and adherence of calcific nodes to bronchi and pulmonary vessels may make dissection tedious and difficult In 2 of our patients (Cases 3 and 5), pneumonectomy became necessary due to this type of technical difficulty

Fig 5 C—Operative photograph demonstrating a calcific peribronchial node embedded in the membranous portion of left main stem bronchus

Provided that the preoperative localization of the site of bleeding has been accurate and this area has been resected, the postoperative convalescence should be uneventful Intensive antibiotic therapy throughout the convalescent period has been helpful in controlling pneumonitis secondary to aspiration atelectasis There have been no significant morbidity and no mortality in this group of 12 patients Recent communications from each of these patients have indicated that there have been no further bleeding episodes

In spite of extensive dissection and pathologic investigation of the excised pulmonary tissue the exact point of bleeding and the bleeding vessel have rarely been demonstrated. Special examinations including plastic bronchovascular cast injection preparations, serial celloidin sections and extensive examination of the bronchial walls under a dissecting microscope have failed to identify the lesion. Roentgenograms of the excised pulmonary tissue may be of value in demonstrating occult peribronchial calcifications which could not be seen on routine chest roentgenograms and could not be identified by palpation in the excised specimen (Fig. 6).

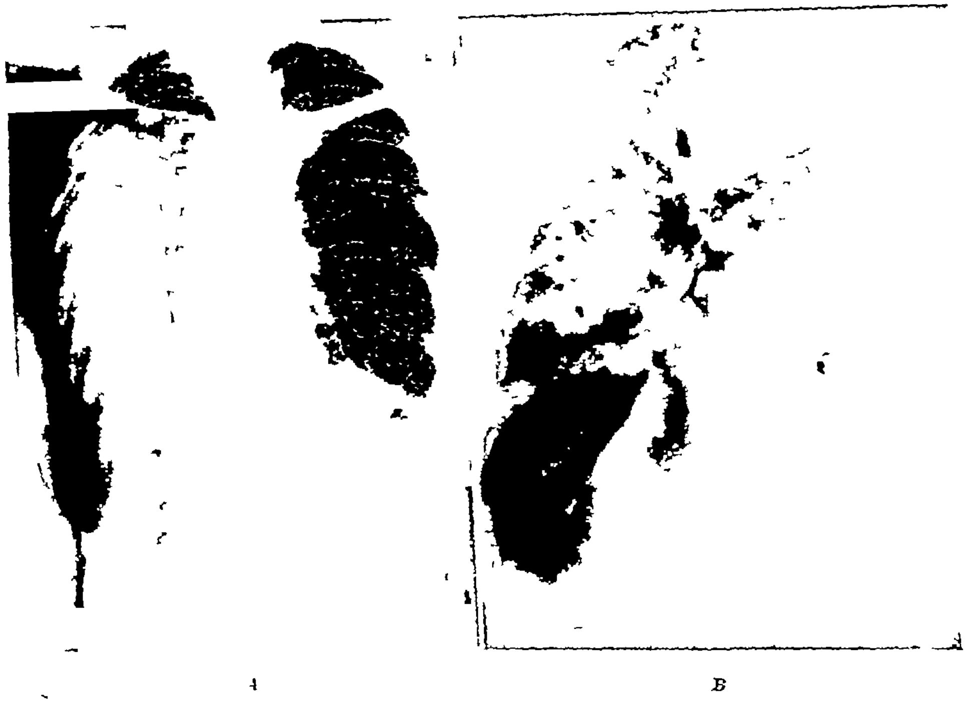


Fig. 6.—Case 3. *A*, Chest roentgenogram demonstrating aspiration pneumonitis in area of left lower lobe. *B*, Roentgenogram of excised left lung. Note multiple areas of calcification in lung parenchyma of superior segment left lower lobe. Partial atelectasis of left lower lobe and obstructive emphysema of left upper lobe.

SUMMARY

The problem of the management of massive life-threatening hemoptysis due to nonmalignant and nontuberculous disease has been presented. In our opinion massive hemoptysis constitutes an indication for thoracotomy as soon as localization of the bleeding site has been established. Preoperative diagnostic procedures for localization of the site of hemorrhage are described. Bronchoscopy during an episode of bleeding is essential. Information gained by this investigation will guide the rational surgical management to a great extent and prevent unnecessary sacrifice of pulmonary tissue inasmuch as operative findings in themselves are often misleading. Broncholithiasis or calcific peribronchial lymph nodes were found to be one of the more frequent causes of massive pulmonary bleeding. Resection therapy in the treatment of these patients has resulted in a low morbidity rate and no mortality

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DISCUSSION

DR RICHARD H. MEADE, Grand Rapids, Mich —I have been interested in the report of the successful culture of organisms in these cases In my own experience, in the three hospitals in which I work in Grand Rapids, they are never able to isolate organisms, as in all cases antibiotics have been used I should like to ask the essayist if he has any special method whereby he is able to obtain these positive cultures

DR FELIX A HUGHES, Jr, Memphis, Tenn —A rare cause of life endangering hemorrhage is aspergillosis

A 56 year old Negro had frequent severe hemoptysis Chest x ray showed an air crescent about a density, reputed to be diagnostic of an aspergilloma Lobectomy was performed with a cure for eight months now A slide shows the gross lesion demonstrating a black mass of mycelia in a large dilated bronchus The next slide is a low power photomicrograph showing extension into the smaller dilated bronchi, and the last one is a Gridley stain showing an Aspergillus spore head The diagnosis may be made by the bacteriologist, and lobectomy is the present treatment of choice

DR CLIFFORD F STOREY, Portsmouth, Va —I would also like to call attention to a rather unusual cause of fatal pulmonary hemorrhage I recently had under my care, within a month's time, two patients whose histories are so nearly identical that I think I can discuss them together One was a 31 year old former Wave, the mother of six young children, who had been apparently well until three weeks prior to admission to the hospital At this time she began to have lassitude, a low grade fever, and repeated small hemoptyses The other patient was a 24 year old man and his illness also began with hemoptysis, which had started in small amounts three weeks before admission At the time of their admission to the hospital both these patients were acutely ill with high fever, marked dyspnea and they were raising large quantities of blood

A chest roentgenogram showed extensive involvement of all lobes of both lungs with widespread miliary and nodular lesions, in the apex of the right upper lobe a large rounded confluent lesion can be seen The nature of these lesions remained in doubt until they were studied histologically after post mortem examination This particular x ray is that of the 31 year old woman The appearance of the young sailor's x ray was exactly the same except that he had no confluent apical lesion

A color photomicrograph showed the alveoli filled with blood The difference between this histologic section and that from a patient who died of ordinary pulmonary hemorrhage is that the alveolar walls are intact in the latter instance whereas in this case the alveolar walls were largely destroyed In two or three areas necrotizing arteritis were noted

Both these patients either were exsanguinated or suffocated as a result of profuse pulmonary hemorrhage Each died within twenty four hours of admission to the hospital The woman died while a bronchoscope was being obtained, the plan having been to do an emergency bronchoscopy followed by a pulmonary resection as soon as the site of bleeding could be determined The second patient was taken to the bronchoscopy room but his hemorrhage was so profuse that it was necessary to perform an emergency tracheotomy in order to carry on aspiration so that he would not drown in his own blood We could not keep ahead of the bleeding, however, and this patient also succumbed

A complete post mortem examination was done in each of these cases and thorough study of the autopsy material showed the classic findings of Wegener's granulomatosis This disease is characterized by three cardinal findings the first consists of granulomatous lesions which may involve any or all parts of the respiratory tract, both upper and lower, from the nasal mucous membranes to the alveoli and including the pharynx, larynx, trachea, bronchi, bronchioles, and pulmonary parenchyma The second classic feature is necrotizing vasculitis involving the smaller arteries and veins in the lungs, kidneys, and various other parenchymatous organs The third cardinal manifestation is a necrotizing glomerulitis This disease appears to be almost invariably fatal and the patients who do not die of hemorrhage most frequently die as the result of renal failure Wegener's granulomatosis bears considerable resemblance to periarteritis nodosa but there are certain features which distinguish one from the other and most pathologists believe that they represent two distinct entities The cause of this disease is unknown but the prevailing opinion is that it is due to some type of hypersensitivity phenomenon The pulmonary lesions in these cases are invariably bilateral and surgery obviously has nothing to offer patients with this disorder

DR GABRIEL SELEY, New York, N Y—I would like to ask the essayists three questions first, what was the extent of the resection in each of the patients in the broncholithiasis group, second, did any of these patients give a history of expectoration of stones and, third, have they had any experience or success with bronchoscopic removal of these stones?

DR HARRY R DECKER, Pittsburgh, Pa—About 20 years ago I had occasion to take care of a man 32 years of age who had been in perfect health He was working as a baker and had had a fall against the sharp edge of a carrier, striking the right side of his chest He developed immediate hemoptysis and was hospitalized He continued to have frequent small hemorrhages Rest and sedatives did not control them, and he was not responding adequately to transfusions, so we planned what was thought to be a conservative operation, a phrenic crush Just as we were about to take him to the operating room he had a massive hemorrhage of about 500 c c We proceeded with the phrenic crush operation I might say that efforts had been made to produce an artificial pneumothorax but not too successfully, since there were adhesions at the base which prevented an effective collapse He got through the operation, which was a minor procedure, successfully The major source of bleeding was controlled Within a year or so he developed what was apparently infiltration in the lower right lobe at the site of the original lesion One positive sputum for tuberculosis was obtained We felt at that time, before the days of successful pulmonary resection, that a plombage operation would be of some merit in controlling this condition We did another phrenic crush operation because there was some movement of the diaphragm, and then inserted about 500 Gm of paraffin

The subsequent history is interesting Whatever lesion he had, whether tuberculous or not (but presumably so because there had been one positive sputum) was controlled He went to visit relatives in Germany in the year 1939 and did not get out of Germany He was drafted into the German army in spite of his history and in spite of carrying a 500 Gm pack of paraffin He got through the war working in a labor battalion without any upset I saw him as recently as two months ago, in good health and doing eight hours' work in a Pittsburgh mill

DR JOHN F HIGGINSON, Portland Ore—In the past seven years we have had occasion to see a total of 90 patients with unexplained hemoptysis varying from several teaspoonfuls to several cupfuls Fifty nine of these patients were seen at the Veterans Hospital and 31 were private patients It is interesting that 5 of these patients had hypertensive vascular disease but we did not know whether or not this is significant

There was no evidence of tuberculosis, neoplasm, bronchiectasis, or cardiac disease in any of these patients, but some did have clinical evidence of some degree of pulmonary emphysema

All the patients were bronchoscoped Many had bronchography in addition On occasion, bronchoscopy is surprisingly disappointing The patient may be raising blood while topical anesthesia is induced, but upon bronchoscopy no evidence of blood can be found or seen even with coughing efforts on the part of the patient In the one case that came to surgery in this group of 90, the source of the continued massive bleeding could not be found in the removed right upper lobe even though blood had been seen pouring from the orifice immediately before operation The patient was apparently cured by the surgery We have thought and still think that most of these otherwise unexplained hemorrhages are the result of rupture of small blebs or bullae not radiographically visible on ordinary chest x rays

DR KARL P KLASSEN, Columbus, Ohio —Recently 3 patients have come under our observation who had massive pulmonary hemorrhage on the basis of unilateral complete thrombosis of the superior and inferior pulmonary veins The first was a patient with a mediastinal granuloma caused by actinomycosis He had extensive venous return from the lung through the bronchial and pleural veins This patient died due to massive blood loss immediately following a pneumonectomy The second patient had a similar condition, however, the causative agent of this lymphadenopathy could not be demonstrated This woman had a pneumonectomy and has been well since that time In the third patient, we were able to demonstrate the complete thrombosis of the right pulmonary veins by preoperative angiocardiography We considered performing an anastomosis between the left atrium and the thrombosed pulmonary veins, however, technically this could not be accomplished Such procedure probably would reduce the venous pressure sufficiently to prevent future hemorrhages We hope to be able to perform this procedure when such an opportunity presents itself in the future

DR CLARENCE CRAFOORD, Stockholm, Sweden —In cases of the type presented in this paper, as in all cases where there is a risk of "spilling over" from the diseased to the nonaffected side, the use of a double barrelled catheter is, in our opinion, the only safe means to avoid complications We consider the one constructed by Carlens to be by far the best If necessary, adequate ventilation and anesthesia can be provided for through the part of the double barrelled tube that leads to the nonaffected side, and continuous suction can be carried out on the diseased side We now use the Carlens tube as an anesthetic tube routinely in all all cases of resection for tuberculosis and have had very gratifying results in several hundred cases

DR DAVID H WATERMAN, Knoxville, Tenn —I wish to report another case of massive hemorrhage occurring in a middle aged woman some 12 years ago She had completely negative x ray findings until we detected a small area of rib erosion laterally On exploration, we found osteomyelitis of the rib with a sharp pointed sequestrum lacerating the lung, which caused the severe bleeding—certainly an unusual cause of hemoptysis

As has been pointed out, bronchoscopy should be done while the patient is bleeding There is a question about this in the minds of many of our bronchoscopists, who feel that bleeding is a contraindication to bronchoscopy Actually it is a very strong indication The risk of bronchoscopy is negligible, we have had no deaths in several hundred patients bronchoscoped while bleeding, and only two deaths in our entire series of some 10,000 bronchoscopies

DR ALFRED GOLDMAN, Beverly Hills, Calif —It seemed to me as I listened to the essayists' excellent discussion, that the problem concerns the indications for operation in massive hemoptysis It is not only probable that we must try to identify the bleeding source but also to consider whether indication for thoracotomy and possible pulmonary resection exists I should like to speak for a moment about the possible indications and nonindications for operation in broncholithiasis We have seen probably 40 or 50 patients with broncholithiasis with one or more hemorrhages Of the entire group, we have operated on only 3 or 4 Some of the patients that we have been following for many years without operative intervention have had one or more massive hemoptyses at the onset The bleeding may cease and not recur for many years This cessation of hemoptysis is most likely in the great majority of patients But in a few the bleeding is alarming and persistent, these form our operative group If the bleeding persists over several days and does not stop with rest antibiotics and sedation, we are prone to consider emergency thoracotomy or resection even though the visible radiologic lesion is no more than calcification (broncholithiasis) Emergency thoracotomy is also preceded by bronchoscopic tracheobronchial toilet under Pentothal anesthesia with a careful search for segmental lobar, stem bronchus or tracheal sites of origin of the hemoptysis

In one of our patients who had an alarming continuous hemorrhage of one week's duration, the right lung was determined by bronchoscopy, to be the source of bleeding but the x ray films of the chest failed to disclose calcification We were dismayed that careful search by the pathologist of the entire right lung which had been removed as an emergency measure, did not reveal a definite bleeding point although the bronchial tree was clogged with blood clot giving the same appearance as the specimen shown by Dr Taber Fortunately for us this young mother recovered from her emergency right pneumonectomy and has since borne two children without another episode of hemoptysis

DR G A. DODDS, Fargo N D—I arise merely to point out that massive hemoptysis may be a manifestation of systemic disease as exemplified by a recent patient of mine a woman aged 55 who presented with a massive pulmonary hemorrhage which was finally localized to the anterior segment of the left upper lobe This segment was resected Frozen sections at the time showed nothing to account for the pulmonary hemorrhage The final sections showed that this was periarteritis nodosa the pulmonary hemorrhage being the presenting symptom of a systemic disease I think the point should be made that resection in massive hemoptysis should be of limited extent where the cause is not readily apparent as one may be dealing with the manifestations of a systemic disease and may needlessly sacrifice lung tissue

DR JAMES DAILEY Houston Texas—Unexplained hemoptysis is a serious and disturbing condition I have seen a number of cases in the past five or six years in which all attempts to find the cause of the bleeding have failed Bronchoscopy and bronchogram studies were noncontributory and the only significant finding in all patients observed was transient or intermittent hypertension Dr Higginson mentioned hypertension in some of his cases I wonder if any others have considered the possibility of a *transient* hypertension causing the bleeding in these cases Some patients will have a systolic blood pressure of 170 or 180 and a diastolic pressure of 100 or more, then maybe a week or so later the pressure will be normal It seems to fluctuate in association with the bleeding episodes The pressure in the bronchial arteries is naturally systemic and often bronchoscopic examination will reveal small arterioles waving around like angleworms in the mucosa. It is conceivable that in the presence of atheromatous change and a sudden increase in pressure one of these could rupture

DR J I EHRENHAFT (Closing)—I should like to thank all the discussers I would like to point out again that the patients presented were those who have had massive bleeding and presented true emergencies We believe that finding the site of bleeding at the time of exploration without having knowledge by preoperative localization of the site is extremely difficult We have felt that every effort must be made to localize the area of hemorrhage as previously outlined

We have not used the double lumen catheter mentioned by Dr Crafoord but we have used intubation of the left or right main bronchus as it might be indicated To answer Dr Seley's question we encountered 6 patients with broncholithiasis in this group Of those two had right lower lobectomies one a left lower lobectomy one patient a pneumonectomy one patient a segmental resection of the lingula only and in one patient the calcific node eroding into the left main bronchus was removed without necessitating pulmonary resection

THE SIGNIFICANCE OF THE ANTERIOR SEGMENT IN BRONCHIECTASIS

RICHARD H OVERHOLT, M D ,* AND WILFORD B NEPTUNE, M D ** (BY INVITATION)
BOSTON, MASS

IN THE evaluation and therapy of pulmonary disease, the possibility of an abnormal anterior segment should not escape attention In tumor, abscess, cyst, or other lesions which alter the density of the segment, roentgenographic evidence is rarely overlooked However, in bronchial disease, with negative findings on fluoroscopy and routine chest examination, errors in discovery are more frequent In tuberculosis, the anterior segment is the least frequently involved of the upper lobe segments In bronchiectasis, segments in the basal or mid position attract attention because they are the chief offenders Consequently, most bronchographic techniques are designed primarily to fill the basilar segments, the middle lobe and lingula, with acceptance of an inadequate upper lobe pattern This is unfortunate since our experience with more than 1,450 cases of bronchiectasis indicates that at least 8 per cent have disease in the anterior segment In several patients with definite symptoms, this has been the only segment involved

We have long been impressed with a peculiarity of bronchiectasis in that the amount of disease as demonstrated bronchographically is not always an index of the severity of symptoms produced Paradoxically, rather extensive bronchiectasis does not necessarily produce symptoms, while minimal changes, associated with loss of ciliary action of the bronchial mucosa, frequently may produce distressing symptoms [1]

An explanation for this inconsistency is quite likely to be found in the relationship of the position assumed by the involved segment Dependency of the dilated bronchus has more influence on clinical behavior than the extent of structural alteration Any abnormal segment or subsegment which escapes detection at bronchography and at surgical exploration may contribute to treatment failure or half-cure Unless some of the instillation of contrast medium is done with the patient in the lateral recumbent and prone positions, the upper anterior quadrants often are poorly demonstrated

A complete mapping of all segments as a preliminary step in evaluating any bronchiectatic patient for surgery is obviously important On rare occasions, the anterior segment may be the only abnormal area (Fig 1), however, the most frequent finding will be middle-lobe disease in combination with involvement of the anterior segment (Fig 2) In these cases, the anterior segment or, in particular, the inferior subsegment usually passes forward and downward with the distal portion being in a dependent position similar to the

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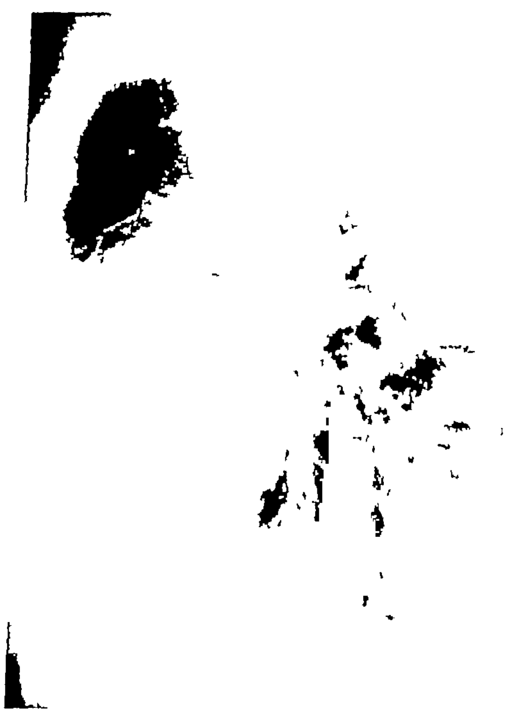

Fig 1

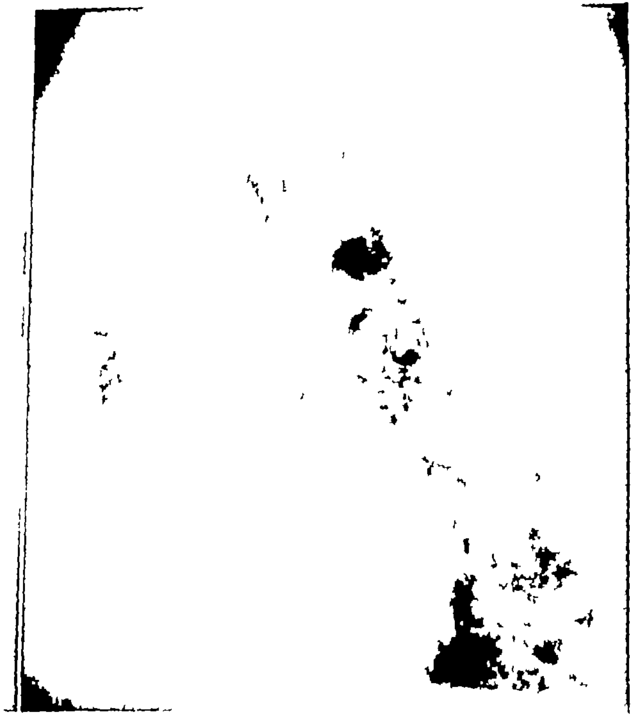

Fig 2

Fig. 1.—Bronchographic demonstration of isolated bronchiectasis in the anterior segment of the right upper lobe

Fig. 2.—Bronchiectatic involvement of the right middle lobe together with the anterior segment of the right upper lobe

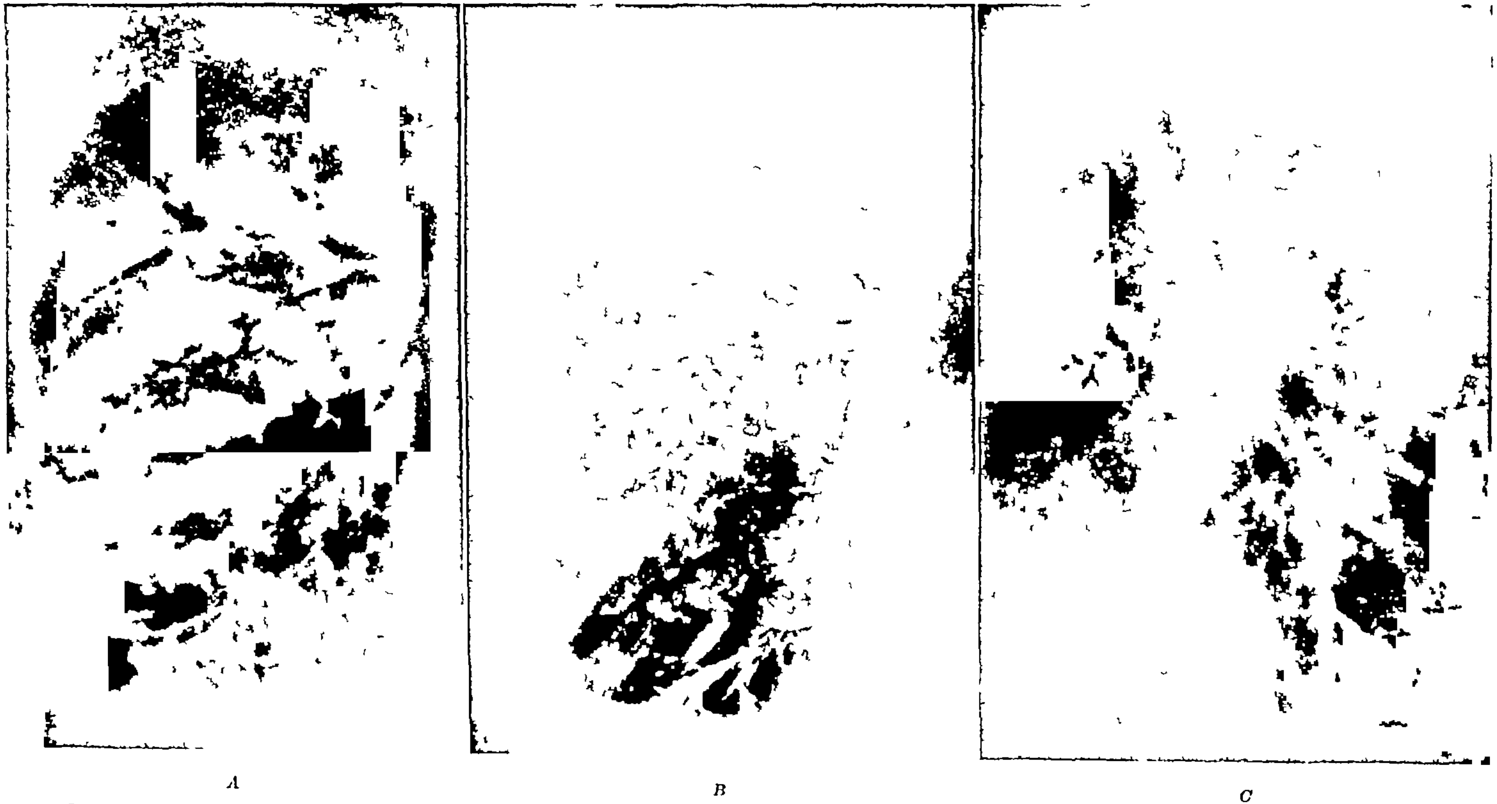

Fig. 3.—*A*, Posteroanterior roentgenogram demonstrating bronchiectasis in the right lower lobe.
B, Oblique roentgenogram showing residual bronchiectasis following segmental resection of the basal group of the right lower lobe.
C, Right lateral bronchogram following resection of the middle lobe. The residual bronchiectasis of the anterior segment has now rotated clockwise to the posterior inferior position.

middle-lobe segments. Clockwise rotation of the anterior segment following resection of the middle lobe, lingula or basal segments brings it into a dependent position. Minimal, pre-existing abnormality is then likely to become a process of pathologic significance. Failure of adequate preoperative evaluation may deny these patients a chance for cure or it may necessitate future surgery to alleviate persistent symptoms.

We have observed patients in whom failure to recognize disease in the anterior segment has resulted in persistence of symptoms after incomplete surgery. Unfortunately, in the past, this has occurred among patients handled initially by us as well as others. The following 2 cases illustrate some of the problems associated with initial oversight.

CASE 1.—A. M., an 18 year old white woman, was first examined on Oct. 1, 1945. At this time she complained of repeated bouts of pneumonia, right chest pain, hemoptysis, cough, and the production of purulent sputum which had been progressive for five years. Physical examination revealed decreased excursion and coarse râles over the right lower lung field.

Bronchography revealed a normal left lung and extensive saccular bronchiectasis of the right basilar segments. There were minimal changes in the middle lobe (Fig. 3, *A*).

Surgery was advised and basilar segmental resection of the right lower lobe was performed in November, 1945. At the time of exploration, the upper and middle lobes and superior segment were found to be normal to inspection and palpation, and they inflated and deflated evenly and promptly. Therefore, the extent of the resection was limited to the basal group.

Following surgery, the patient did quite well and was greatly improved, yet a slight productive cough persisted. Two years later, she again developed an increase in cough with production of more sputum and frequent upper respiratory infections. A repeat bronchography was *done in May, 1948*, and definite bronchiectasis *of the middle lobe and* superior segment of the lower lobe was demonstrated (Fig. 3, *B*).

In July, 1948, the middle lobe and remaining superior segment of the lower lobe were amputated by carrying the resection through the intermediate bronchus. Again the patient made an excellent recovery and was improved until February, 1954 (six years later), when she developed an extremely irritating cough which was intractable to all medical therapy.

Repeat bronchograms again revealed a normal left lung, but the anterior segment of the right upper lobe, which was now rotated clockwise to occupy the posterior inferior portion of the right hemithorax, was the site of extensive tubular and saccular bronchiectasis (Fig. 3, *C*). We learned from a review of previous bronchograms that the anterior segment had not been filled at that time. *In April, 1954, the anterior* segment was resected. The patient states that she is now free of all symptoms for the first time since the onset of her difficulty in 1940.

CASE 2.—N. B., a 34 year old white woman, was first seen on May 12, 1954. She had a history of hemoptysis, cough, and the production of purulent sputum since 1938. In 1945 she had had a resection of the right middle lobe and basilar segments of the right lower lobe in another hospital. Following surgery, cough and purulent sputum persisted. There were occasional attacks of hemoptysis. By x-ray the right diaphragm was very high and the lung field largely obscured. Laminography demonstrated multiple cavitary areas in the mid-portion of the right lung field. A repeat bronchogram revealed extensive bronchiectasis of the lingula and left basal group. This was essentially the pattern of the disease on the left as found in the 1945 bronchograms. On the right side there was an absence of middle and basal segments with marked crowding and reduction in the volume of the superior segment. There was cavitation in the *upper lobe*. Interpretation as to the extent of the destructive process and an appraisal of functional capacity of any remaining segments on the right was difficult *due to the intense pleural* reaction, the distorted bronchial pattern and parenchymal cavitation (Fig. 4, *B* and *C*).

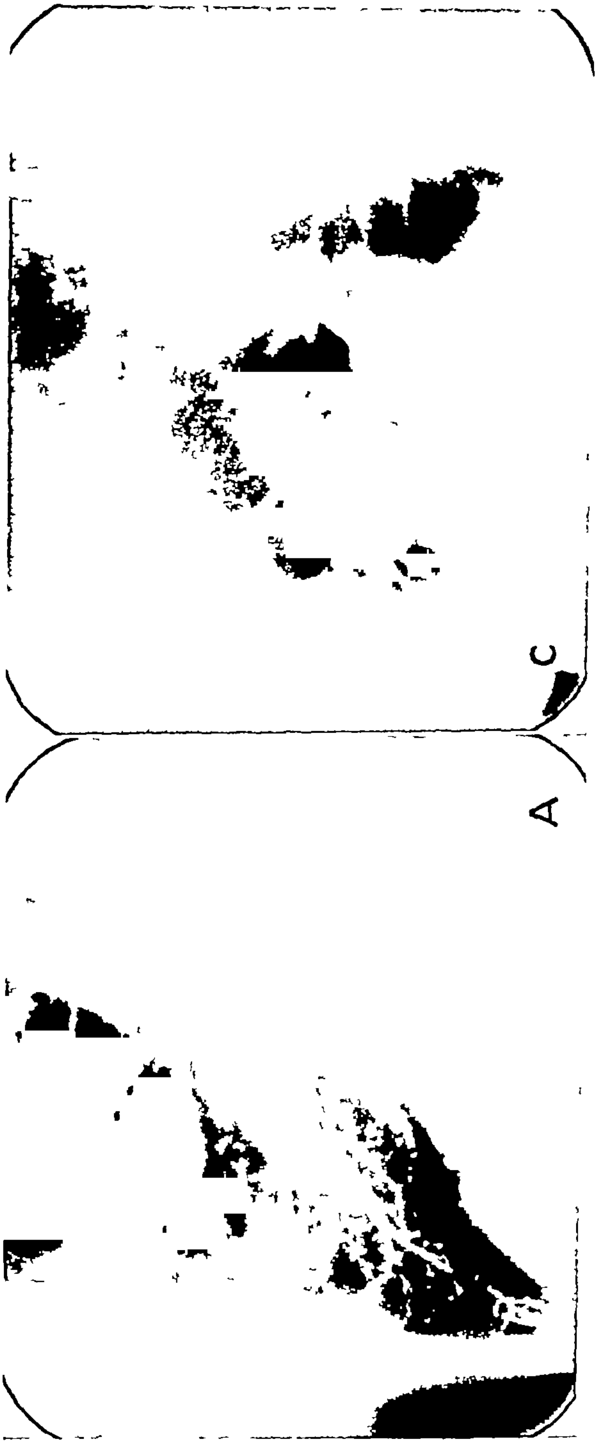

Fig 4 A and C (For legend see opposite page)

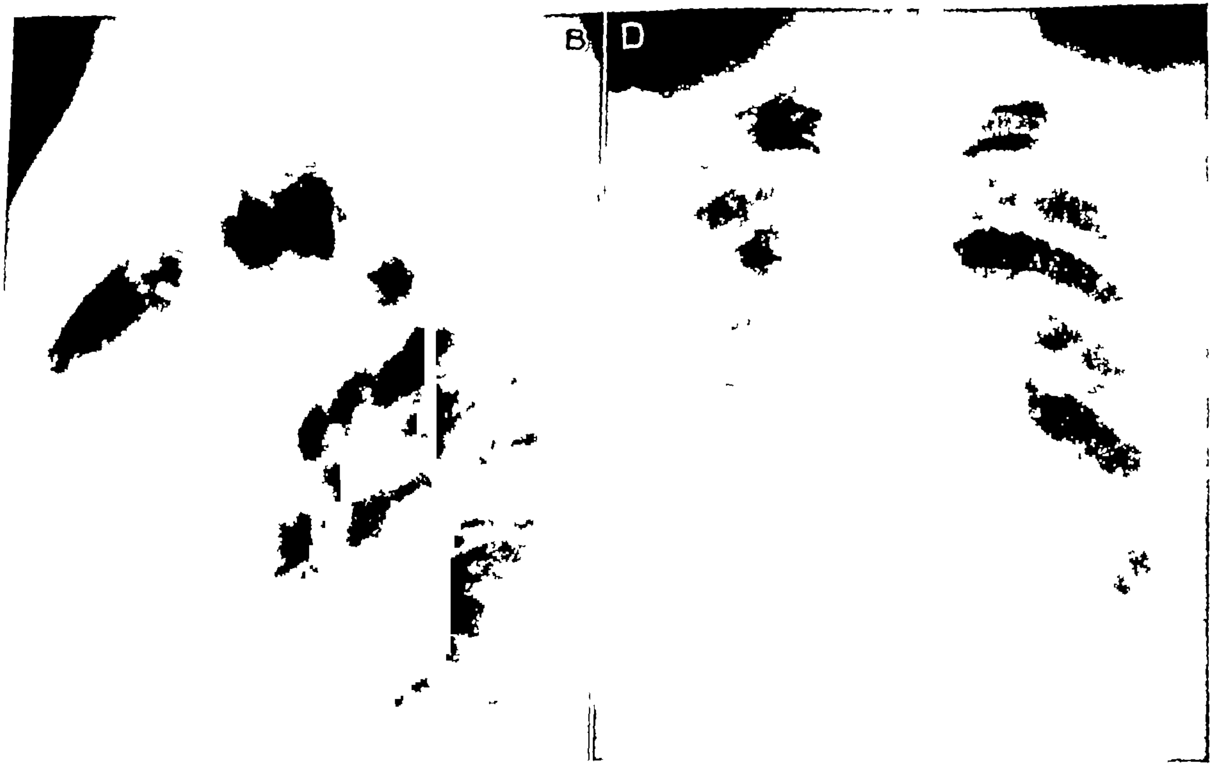

Fig. 1.—*A* Spot film bronchogram (uncropped) showing abnormality of the right lung Other spot films taken were also of insufficient size to demonstrate possible abnormality of the upper lobe

B Right lateral roentgenogram demonstrating the large abscess in the mid lung area. The patient previously had had resection of the middle lobe and basilar segments of the lower lobe

C Spot film bronchogram eight years following first operation Residual bronchiectasis is demonstrated Evaluation is difficult because of anatomic distortion and limitation of field

D Roentgenogram following left upper lobectomy The right hemithorax contains only the superior segment

A review of the bronchograms in 1945 revealed extensive bronchiectasis of the right lower lobe with incomplete visualization of the remaining lung fields due to the fact that the study was based upon spot film technique (Fig 4, *A*)

In May, 1954, after right exploratory thoracotomy and decortication, the residual superior segment of the lower lobe was found to be in good condition The anterior and posterior segments of the upper lobe, however, contained a large abscess cavity with surrounding induration The apical segment was emphysematous and trapped air Since there was such extensive involvement of the entire upper lobe, this lobe was resected The remaining superior segment of the lower lobe filled the remaining thoracic space well

The patient made an excellent recovery and is now free of symptoms (Fig 4, *D*)

TECHNIQUE

Technically, the right or left anterior segment can be removed individually or in combination with adjoining segments about as easily as any of the other 16 segments When an anterior segment or a subsegment of it and the middle lobe are involved (the most common combination), the minor fissure, if present, is usually fused by the inflammatory process Both lobe and segment can be enucleated together *with greater facility and safety* than by resection of the middle lobe alone The same applies to involvement of the lingula and the inferior subsegment of the anterior or the entire anterior segment on the left side Both segments can be removed together with greater ease and safety than by resection of the lingula alone if both are diseased As in all types of pulmonary resection, the *entire lung should be completely mobilized* This permits better visualization, palpation and finger-and-thumb control of the structures of the hilum

The technique that we have found useful in the combined enucleation of the middle lobe and anterior segment or the lingula and anterior segment is as follows

1 The middle lobe is detached at its hilum without disturbing its anchorage to the upper lobe The distal cut end of the bronchus is held with an Allis forceps which is used for gentle traction (Fig 5)
2 The inferior surface of the superior vein is dissected Usually, small tributaries require ligation (posterior and anterior interlobar veins) (Fig 5 insert)
3 The visceral pleura at the base of the great fissure and at the apex of the middle lobe is divided If lymph nodes are present, they should be removed This bares the pulmonary artery near the take-off of the superior segment and recurrent vessels The anterior segmental artery is slightly higher and anterior to the segmental bronchus
4 The left hand is inserted beneath the lung to hold the middle lobe and segment The left thumb or right forefinger locates the segmental bronchus With gentle traction on the segment and slight pressure between finger and thumb, it is an easy matter to palpate the anterior segmental bronchus Sharp dissection with scissors is used and a 1 cm length of it is cleared The bronchus is then divided The artery immediately comes into view and can be likewise treated (Fig 6)
5 Attention is next given to the vein Gentle traction on the divided bronchus and artery in a downward and anterior direction will aid in finding branches

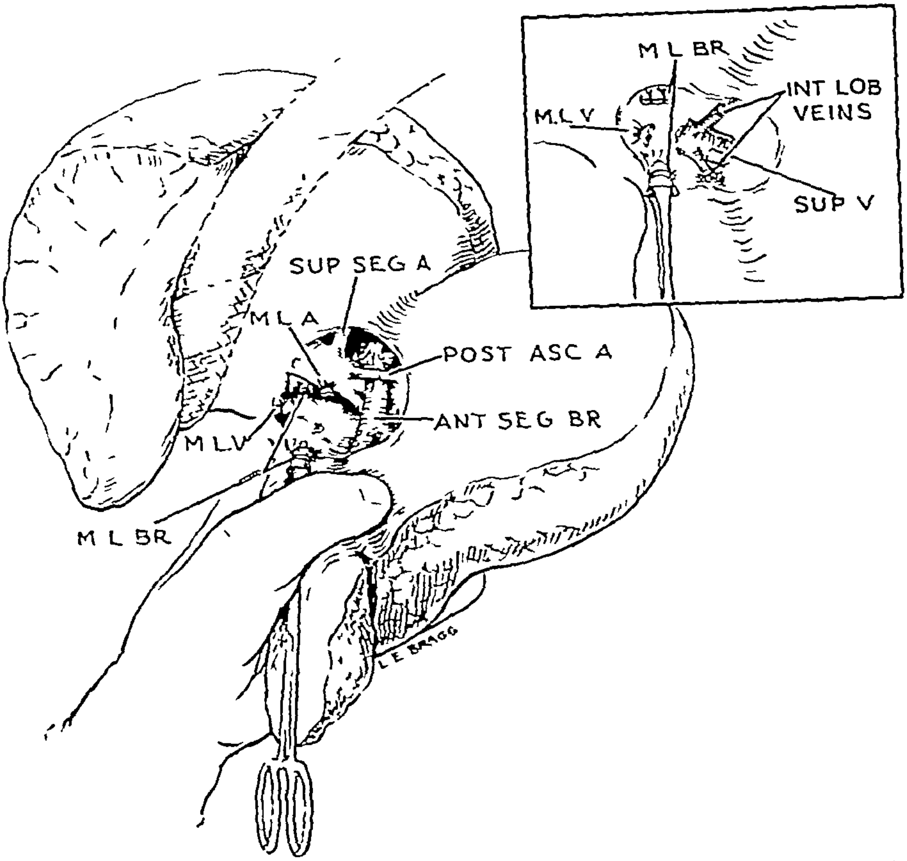

Fig [illegible] —Early stage of dissection of anterior segmental hilum when this segment and the middle lobe both require resection The structures of the middle-lobe hilum have been divided This lobe is left attached to the undersurface of the anterior segment and serves for traction The pleural reflexion at the base of the great fissure is divided and segmental arteries and branches of the anterior segment exposed The insert shows the position of small interlobar veins that are frequently encountered. The superior pulmonary vein should be identified early in dissection

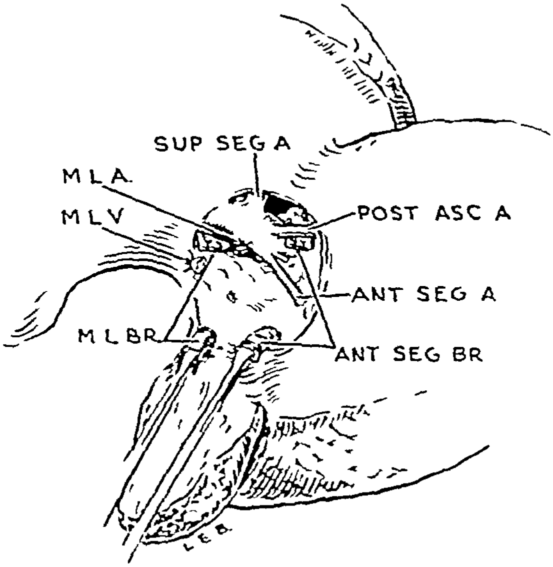

Fig [illegible] —After the anterior segmental bronchus has been divided traction upon it facilitates exposure of the segmental artery Note that the stump of the anterior bronchus is between the main pulmonary artery and the posterior ascending artery

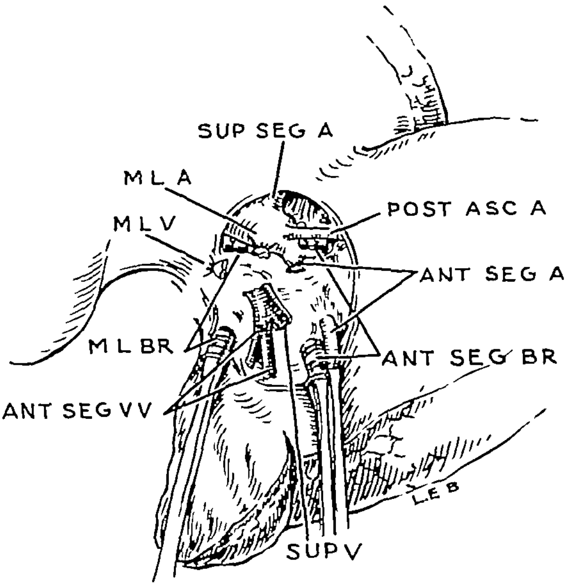

Fig 7—After ligation of the anterior segmental artery the superior vein and its branches from the anterior segment come into better view

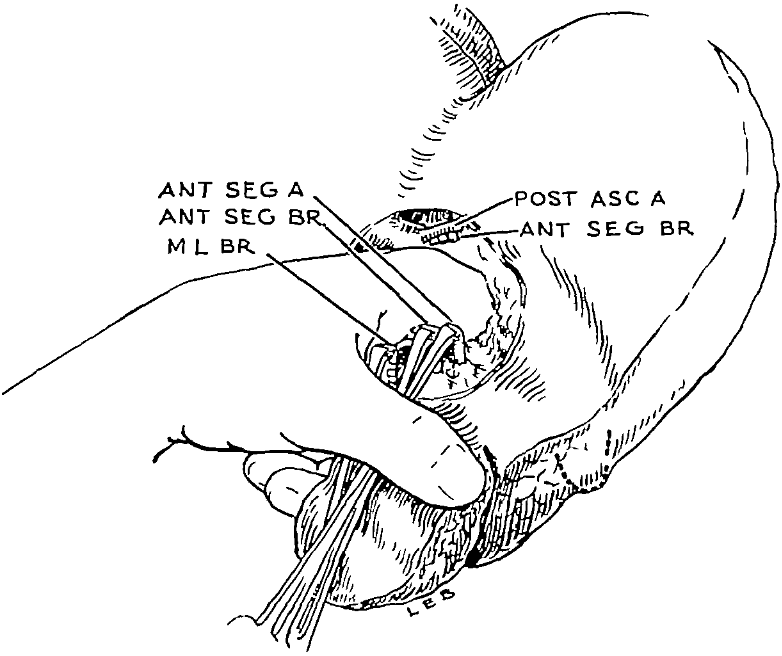

Fig 8—The intersegmental plane is dissected with the finger The middle lobe and anterior segment are held in the palm of the hand A forceps on the severed bronchus is used to hold the segment in approximately its original position If the normal relationship between the segment to be removed and the adjacent healthy segment is maintained the index finger will more easily find the proper cleavage plane between them The finger is gently pushed through to the pleural surface in several directions which form tunnels between segments The pleura is then opened where the finger tip surfaces The spaces between the tunnels can be readily joined by expression between thumb and forefinger Intercommunicating veins create slight resistance which leads to their identification They should be individually ligated

of the superior vein which drains the anterior segment as they are placed on slight tension They are quickly disposed of We have found it helpful to use ligatures on the vessels on the specimen side for traction Those on the veins serve as guides to the intersegmental plane (Fig 7)

6 The lung is inflated and the clamp on the anterior segmental bronchus is held in such a manner that the anterior segment and the middle lobe (now attached by only the intersegmental surface) assume their normal anatomical position The index finger of the left hand is slipped above the bronchus and divided veins and gently pushed through to the visceral pleural surface (Fig 8) The finger follows the path of least resistance and finds the proper plane This maneuver is repeated two or three times in different directions so that tunnels are formed in the area of the intersegmental plane With thumb and forefinger the intervening parenchymal tissue is pressed together

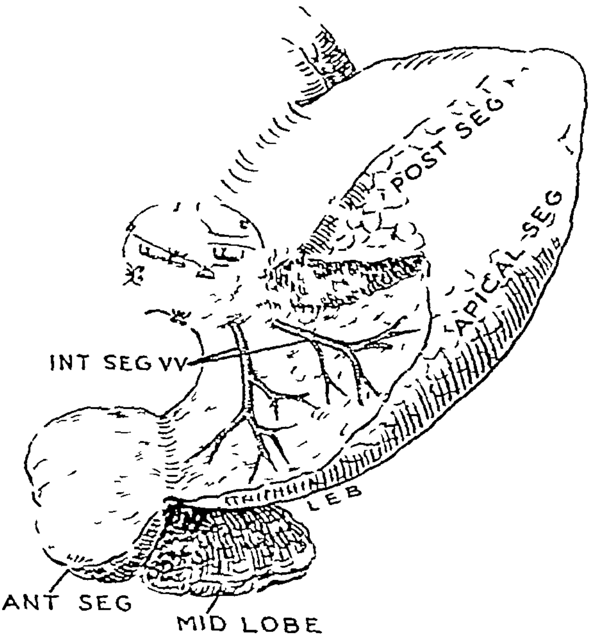

Fig 9—Final stage of the combined resection of the middle lobe and the anterior segment with only a small section of pleura still attached anteriorly The denuded surfaces of the posterior and apical segments and the usual appearance of the preserved interlobar vein are shown

Soon the adjoined segments melt down to a few thin strands of tissue, some of which are intercommunicating veins These are ligated before they are torn or divided (Fig 9)

7 In most instances the denuded surface of the posterior and apical segments is automatically covered by the visceral surface of the expanded lower lobe which brings the visceral surface of the *major* fissure into contact In the event of clockwise expansion and rotation of the apical segment due to marked contraction of the anterior segment the denuded surface may be

half-moon or wedge shaped If so, the edges can be fastened together to give a complete visceral pleural covering to the remaining two segments of the upper lobe

For the single enucleation of the anterior segment, these technical steps are usually followed

1 The great fissure is developed It is not necessary to pay any attention to the minor fissure at this point
2 The pulmonary artery is cleared of lymph nodes The posterior interlobar vein is divided, if present The superior and posterior ascending segmental arteries are identified
3 The left hand holds the middle lobe and the fingers are passed in front of the anterior segment The bronchus is palpated and dissected
4 The anterior segmental artery and veins are ligated and divided Traction is *made on the divided bronchus to return the segment to its normal* position
5 After inflation of the lung, an incomplete or absent minor fissure presents no problem The dissecting finger finds the proper plane between lobe and segment, then between the anterior and the posterior segments and, finally, the plane between the anterior and apical segments is developed The single enucleation is then completed

SUMMARY

1 In our experience among those patients with bronchiectasis in whom surgery is required for treatment, about 8 per cent have involvement of the anterior segment of the right or left upper lobes

2 While the anterior segment may be the only area involved, the most frequent finding is the combination of middle-lobe disease together with the anterior segment Likewise, involvement of the lingula and left anterior segment is more common than involvement of the left anterior segment alone

3 Failure to recognize structural change in the anterior segment may contribute to a surgical failure or half-cure

4 Cases are presented to illustrate the consequences of initial oversight requiring reoperation

5 The technique for the removal of the anterior segment alone or together with the middle lobe or lingula is presented

6 The ideal bronchographic examination will demonstrate every pulmonary segment It should offer several comparative positions of the entire thorax *The right lung should be filled first so that an unobstructed* lateral film may be taken Oblique films with bilateral filling should be taken without overlapping of the two lungs Fluoroscopy should not be used diagnostically but only as a guide to a complete pattern Technical and human factors may sometimes deny the ideal, but its achievement should always be attempted

REFERENCE

1 Overholt, Richard H, Woods, Francis M, and Atwell, Sherman W Paradox of Bronchiectasis, J A M A 154 193 196, 1954

DISCUSSION

DR ARTHUR M. OLSEN, Rochester, Minn —Dr Overholt and Dr Neptune have brought to our attention the great importance of making complete bilateral bronchograms in the presence of bronchiectasis Unless the bronchi of the upper lobes are adequately filled with contrast medium, significant bronchiectasis in the anterior segments may be overlooked Recently my colleagues and I have completed a study of a series of 221 patients with bronchiectasis on whom surgical resection was carried out We were particularly interested in analyzing our unfavorable results We found that a number of our early patients had not had adequate preoperative bronchography and that in several instances postoperative bronchograms revealed bronchiectasis in the anterior segments after resection of the lower portion of the lung had been done The preoperative and postoperative bronchograms of one of these patients are shown on a slide

In an analysis of our cases, the fact becomes evident that the surgeon must remove all the tissues affected by bronchiectasis in the lung on which he operates If disease remains in the lingual or middle lobe or in the anterior segments of the upper lobes, marked increase in bronchial dilatation can be anticipated and often the problems of retention of sputum will be greater than before operation For some of our early patients a second operation was necessary to remove residual disease bearing tissue that had been left behind in the lung operated upon at the time of the initial procedure On the other hand we found that bronchiectasis in the contralateral lung often is well tolerated and can be controlled with antibiotic therapy

The importance of complete bronchography for patients with bronchiectasis who are to undergo surgical resection cannot be overemphasized Bronchography must be repeated if adequate filling is not obtained at the time of the first examination The use of the newer water soluble bronchographic media has made it possible to repeat bronchograms at relatively short intervals

SPONTANEOUS RUPTURE OF THE ESOPHAGUS

With Presentation of Four New Cases

George W. B. Starkey, M.D. (by invitation)
Boston, Mass.

IN SPITE of the fact that this subject has been discussed many times in the past, the mortality rate of spontaneous rupture of the esophagus is still too high. The reasons for this continue to be the same as in the past, namely, the diagnosis is not made soon enough, and, proper treatment is instituted too late. With this thought in mind, I would like to discuss the problem and briefly present 4 cases which were seen within the last eighteen months.

In 1724, Boerhaave[1] dramatically recorded the case of Baron van Wassenaer, the Grand Admiral of Holland, who died of a ruptured esophagus. Since that account, Moynihan[2] has reported that some 200 cases have been published. By 1952, 134 cases were reported with 27 survivals. There have been many excellent accounts in the literature on this subject, notably those of Walker,[3] Barrett,[4] Olsen and Clagett,[5] Eliason and Welty,[6] Kinsella, Morse and Hertzog,[7] Lynch,[8] Ware and Strieder,[9] Priviteri and Gay,[10] Samson,[11] Mackler,[12] Anderson,[13] and others.

I agree with Samson[11] that these ruptures of the esophagus have not been truly "spontaneous," i.e., they have not occurred without some extrapleural provocation, the principal one of which has been vomiting. Although this is not one of the common medical emergencies, it is usually catastrophic unless early surgical intervention is instituted, in which case the outcome is usually excellent. To lose a patient with a ruptured esophagus is more than likely due to an error of omission rather than of commission. The correct diagnosis is usually made when the patient is in extremis or after he has died. The most common mistaken diagnoses are perforated peptic ulcer, acute myocardial infarct, spontaneous pneumothorax, acute pancreatitis, dissecting aortic aneurysm, and acute mesenteric thrombosis.

The onset is usually acute. Chest pain is common, located particularly in the back and is aggravated by breathing. There is antecedent nausea and vomiting, or retching. This unremitting pain often radiates to the upper abdomen and shoulders. The patient usually becomes tachypnic and is in a state of shock. The physical examination reveals an acutely ill patient often groaning in agony in spite of heavy medication. He frequently has a spastic upper abdomen and evidence of fluid or fluid and air in the left chest, or occasionally in the right. As the swallowed air escapes from the rent in the

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esophagus it begins to dissect up through the mediastinum into the subcutaneous areas of the neck and face If the perforation extends out into the pleural space it may cause a tension pneumothorax which further endangers the patient X-rays of the chest frequently show fluid levels in the mediastinum and a hydropneumothorax A swallow of 10 to 20 c c of Lipiodol preceding the x-rays almost invariably demonstrates the esophageal leak.

Once the diagnosis is made the operating room should be alerted In the preoperative phase several important things should be done Oxygen and moderate dosages of an analgesic should be given. Any existing hemoconcentration or other fluid and electrolyte imbalance should be corrected Large doses of penicillin and streptomycin or one of the broader-spectrum antibiotics should be given If the patient is in shock and has a hydropneumothorax particularly if under tension closed thoracotomy drainage should be done Often relieving the pleural space of a large quantity of highly irritating fluid and air converts a very precarious situation into a much more tenable one A thoracotomy is done and the esophageal tear is closed with two layers of interrupted fine silk sutures The pleural and mediastinal spaces are drained If the diagnosis is made thirty-six to forty-eight or more hours after esophageal rupture only closed thoracotomy drainage is needed followed by a feeding jejunostomy a day or two later

The pathologic findings are very similar in most cases The pleural space has dark brown fluid and fibrin in it and if the mediastinal pleura has ruptured it may also contain a considerable quantity of gastric contents The mediastinal pleura is frequently fiery red with some areas of gray or brown slough The esophagus has a vertical tear 2 to 5 cm in length in its lateral wall just above the diaphragm On inspection and palpation the esophagus appears to have no underlying disease to account for its rupture

Briefly 4 cases will be presented and discussed

CASE REPORTS

CASE 1 —M F a 45 year old schoolteacher, entered the hospital at 7 00 P M, Aug 30, 1953 with the chief complaint a severe substernal and left chest pain of about 5 hours duration which radiated to the back and left shoulder This was associated with increasing dyspnea. This woman had a fairly benign past history except for a little nausea and slight heartburn two months before entry On Sunday Aug 30, 1953 she had gone to a picnic at the beach She had had a fairly heavy lunch including chicken salad An hour or two later she became nauseated. She then vomited a small amount of fluid and a little blood and immediately noticed severe back pain radiating to the shoulders This increased steadily She thought she was having a touch of "indigestion" and so paced back and forth for a while with no relief She continued to vomit and within about one hour noted swelling of the left side of the face and eyelid This alarmed her and she was driven home The pain and facial swelling increased and with this she became progressively short of breath She called a doctor who had her sent immediately to the hospital where she arrived at about 7 00 P M On the basis of an x ray taken on admission (Fig 1), the initial diagnosis was that of a ruptured bleb of the lung, possibly adherent to the parietal pleura or mediastinal pleura causing extravasation of air into the mediastinum and subcutaneous tissues On sedation and oxygen the patient became worse At 11 30 P M. that evening a thoracic surgeon was called to see the patient Physical examination at midnight showed a very ill slightly cyanotic woman writhing in agony She had extensive subcutaneous emphysema of face, chest, arms, and upper abdomen The blood pressure was 120/68, temperature was 102° F, pulse 120, respirations 24 The rest of the physical examination was not remarkable except for some spasm and tenderness in both upper quadrants, more on the left than the right The operating room was alerted to prepare for a thoracotomy A chest x ray was then taken by portable machine after the patient had swallowed 15 to 20 c c of Lipiodol This x ray clearly demonstrated the leak in the lower end of the esophagus out into the mediastinum without spillage into the pleura itself (Fig 2) In the meantime 1 million U of penicillin, 1 Gm of streptomycin, and oxygen were given and an infusion was started A white blood count at this time showed a marked leukopenia of 2,400

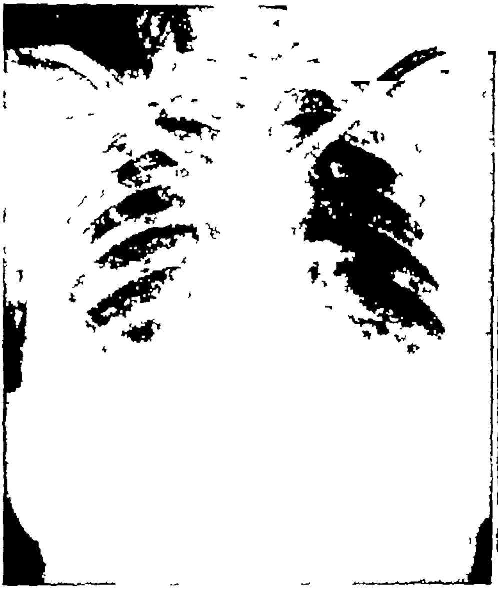


Fig 1

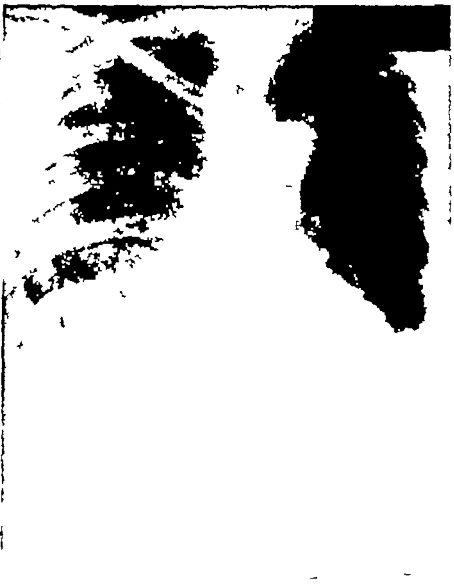


Fig 2

Fig 1—Case 1 (M.F) Admission x ray of the chest which demonstrates subcutaneous and mediastinal emphysema bilateral pleural fluid more on the left and a suggestion of fluid and air behind the heart shadow

Fig 2—Case 1 (M F) Posteroanterior film of the chest after a swallow of Lipiodol which demonstrates the dye passing out into the mediastinum from the lower end of the esophagus

Operation—At 2 00 A M on Aug 31, 1953, about twelve hours after perforation, a left thoracotomy was done When the pleura was opened a considerable amount of dirty brown fluid escaped from the pleural space There were about 1,200 c c of brown fluid and fibrin The medial border of the lower lobe was adherent to the lower mediastinum When this was dissected free, the lower mediastinal was found to be bulging outward but its pleura was still intact This mediastinum pleura was a gray slough extending from the diaphragm to the arch of the aorta This area of slough was resected. When the mediastinum was opened a large amount of fluid, food, and air were liberated into the left pleural space Prior to this maneuver, the patient's blood pressure was about 70/40 but within a matter of a couple of minutes the blood pressure came back to a normal range and remained there throughout the rest of the operation The mediastinum was débrided and a considerable amount of chicken salad was removed from under the arch of the aorta and from other parts of the mediastinum A 3 cm longitudinal tear was found in the esophagus just above the diaphragm This was anterolateral in position There was a small amount of fibrin overlying the muscle but the mucosa was not remark able except for slight reddening A finger was gently inserted into the tear, into the stomach and up into the esophagus No foreign body, ulceration tumor, or hiatus hernia could be palpated The entire pleural and mediastinal spaces were then lavaged with a large quantity of saline The esophagus was closed in 3 layers using No 4-0 continuous chromic catgut for the mucosa and No 3 0 chromic catgut for the muscularis Two or three No 4 0 silk reinforcing sutures for the muscularis were then inserted (I believe the use of a continuous suture was unwise, in spite of some respiratory difficulty during the anesthesia at this time which prompted the operator to elect a more rapid closure of the esophagus) The pleural space was lavaged again. Two thoracotomy drainage tubes were inserted one sutured into the posterior sulcus and one sutured to the diaphragm near the lower end of the esophagus The chest was closed in the usual manner A Levin tube had been placed into the stomach at the time of operation and was removed twelve hours later

Postoperatively the patient's white blood count rose to 9 300 on the first day The drainage tubes were removed on the third day and she was allowed to be ambulant About 1000 c c of dark amber sterile fluid was removed from the right chest on the first postoperative day On the twelfth day a Lipiodol swallow showed no leak and a good lumen so she was put on a regular diet and discharged a day or two later

This patient has done well since except for one interesting complication six weeks after discharge She suddenly was unable to swallow solids after ingesting a piece of rather tough roast beef. She re-entered the hospital A thin barium swallow showed an obstruction of the lower end of the esophagus The patient was therefore esophagoscoped and the roast beef removed. The esophagus appeared normal grossly and was dilated easily with graded mercury bougies up to the largest size immediately after esophagoscopy She has had no further trouble A gastrointestinal series several months later was normal

This patient demonstrated several points

1 The initial diagnosis was incorrect and contributed to a delay of about six hours in treatment

2 Signs and symptoms were quite classical of spontaneous rupture of the esophagus namely, severe vomiting associated with chest and back pain subsequent subcutaneous emphysema and x-ray evidence of a tear in the lower end of the esophagus

3 As mentioned previously it certainly would have been wiser to do an interrupted two layer closure of the esophagus with fine silk than to use a continuous suture in the mucosa This may have accounted for the esophageal obstruction six weeks after discharge

CASE 2—F T a 69 year-old factory worker was admitted to the hospital on April 7 1954 with a chief complaint of abdominal pain and vomiting of one to two days' duration

Present Illness—Two days prior to entry the patient noted some upper abdominal discomfort which he treated symptomatically He then had diarrhea and abdominal cramps which continued for two days He was therefore admitted to the hospital

His past history was not very remarkable except that he had had digitalis prescribed by his own doctor six years before He also had a questionable history of duodenal ulcer several years before entry

In the hospital he appeared to be a chronically ill man, somewhat dehydrated The lungs were clear He had a slow auricular fibrillation apparently on the basis of old rheumatic heart disease The abdomen was slightly distended and had vigorous peristalsis There were slight spasm and tenderness in both upper quadrants The initial diagnosis was gastroenteritis questionable pancreatitis The day after entry the vomiting continued and he complained of pain in the mid back below the left scapula which was aggravated by breathing On the following day he had more spasm in the upper quadrants of the abdomen and a chest film at this time showed a hydropneumothorax. The chest was tapped and 750 c c of dark greenish fluid was removed from the left chest Three days later the abdomen was softer and peristalsis was more normal. He took food poorly and continued to appear very ill The temperature still did not go above 100° F

Seven days after admission, a closed thoracotomy was done on the left and the same dark material was removed Eight days after admission, there was more pneumothorax on the left and the vomiting persisted The patient was given a barium swallow which showed a leak in the lower end of the esophagus The barium passed out over the surface of the left diaphragm A thoracic surgeon was called at that time and a larger tube was used for a closed thoracotomy drainage in the left chest The lung re-expanded in about two days and the closed thoracotomy drainage was converted to an open one as soon as the lung was stuck to the chest wall Drainage continued from this esophageal fistula but became less and less A jejunostomy was performed eleven days after admission The patient began to improve very slowly but, about one month following admission, he suddenly complained of pain in the abdomen, went into shock, and died in a matter of an hour or two

A post mortem examination revealed a perforation of the esophagus with a left empyema The esophagus was not remarkable except for the perforation and there was no evidence of tumor, ulcer, or diaphragmatic hernia The patient also had a large posterior duodenal ulcer which had eroded a vessel in its base The peritoneum was filled with about 1½ to 2 L of blood, gastric contents, and air The ulcer had perforated and massive bleeding occurred from the vessel in its base There was also evidence of severe atherosclerotic coronary artery changes and a questionable recent myocardial infarct

This case presented is a more complicated problem than the first one but it demonstrates several points

1 The patient entered the hospital with a history of vomiting and in a short time developed pain in the back and a left pleural effusion with a hydropneumothorax A chest tap within forty-eight hours from the time of admission showed dark brownish material which might have suggested the possibility of a ruptured esophagus with a leak into the pleural space It was thought then that some air may have entered the pleural space at the time of the thoracentesis

2 It was not until several days later that drainage of the pleural space was instituted and this was made with a small thoracotomy drainage tube

3 Nine days after admission, an esophageal leak was demonstrated by barium swallow At that time the patient had a more adequate drainage of his left pleural space For three weeks after drainage of the left pleural space and mediastinum, he was recovering slowly, when he died suddenly of a ruptured and bleeding duodenal ulcer The actual time from possible rupture of the esophagus until drainage was instituted was eight or nine days Earlier drainage might have saved this patient's life This, of course, is said with the advantage of hindsight in a case that was admittedly far less clear cut than the first one

Case 3—R S, a 52 year old Negro painter, was admitted to the hospital Aug 22, 1954, with a chief complaint of pain in the left chest of approximately six hours' duration The past history was not remarkable

Present Illness—This patient had his usual Sunday morning breakfast after which he lay down on the living room floor to read the paper He was feeling perfectly well when he did this and after finishing the paper he rolled over on his back, yawned, and stretched his arms and legs On doing this, he suddenly had severe pain in the left chest substernally and under the left scapula The pain was made worse by breathing and he became cold and clammy His local doctor was called who thought that the patient had had a myocardial infarction because of his sudden left chest pain, dyspnea, and tachycardia He gave him ¼ gr of morphine and sent him to the hospital He entered at 3 00 P M Physical examination on entry revealed a well developed Negro man in severe pain The blood pressure was 165/85, pulse 120, respirations 36 There was dullness at the left base posteriorly and splinting on that side Both the femoral and radial pulses were readily palpable and normal The heart was not remarkable except for a tachycardia He complained of severe pain in the left anterior and posterior chest increased by respiration He also had some tenderness and spasm in the epigastrium An x ray of the chest at 3 00 P M on the day of admission revealed some fluid at the left base (Fig 3) The diaphragm seemed somewhat elevated There was no air under the diaphragm except in the stomach bubble An electrocardiogram suggested some myocardial ischemia and a tachycardia of 130 Temperature was 100° F He was perspiring and restless The blood pressure came down to 120/80 and the pulse went up to 140 He was given 500 c c of plasma The initial white blood count was 13,500 and hemoglobin 18 Gm Large doses of penicillin were administered At 6 00 P M, he suddenly experienced more pain in the left chest and became more dyspneic At that time the blood pressure was 90/60 and the pulse was 160 An x ray at that time showed a tension hydropneumothorax on the left (Fig 4) Because of the tension hydropneumothorax, a left chest tap was done which revealed dark brownish fluid and air A trochar was introduced in the posterior axillary line and 2,000 c c of fluid and air were removed This relieved the patient somewhat No free hydrochloric acid was found in the fluid removed A thoracic surgeon was called at about 11 00 P M On the basis of the telephone conversation, it was thought that the patient had a ruptured esophagus He was given 20 c c of Lipiodol to swallow and an x ray was taken (Fig 5) This showed a lower esophageal leak into the left pleural space and also into an area that appeared to be under the diaphragm but not in the gastrointestinal tract The patient's pleura was further decompressed with a large bore needle because he was developing more air than was being evacuated by the trochar The latter was removed and the patient was taken to the operating room

A left thoracotomy was made about eighteen hours after perforation Two thousand cubic centimeters of dirty brown fluid and old food were removed from the pleural space A large rent in the mediastinal pleura, 10 cm in length from the diaphragm up toward the aortic arch, was noted There was a considerable amount of fibrinous exudate and air A vertical tear was found in the esophagus 3 to 4 cm in length extending to a point just below the esophageal hiatus in the diaphragm, which may have accounted for the Lipiodol below the diaphragm The mediastinum was debrided and the chest and mediastinum lavaged with large quantities of saline The esophagus was then closed in 2 layers with interrupted No 4 0 silk sutures after palpation of the esophagus in an effort to determine any underlying pathology but none was found The pleura was drained with a large thoracotomy tube One million units of penicillin and 1 Gm of streptomycin were instilled into the pleural space

Postoperatively this patient did very well A Levin tube was used to decompress the stomach for twelve hours He was started on clear fluids by mouth on the second day nourishing fluids on the fourth day, and a soft diet on the sixth day He was kept on 1 million U of penicillin and 2 Gm of streptomycin daily for six days He was discharged from the hospital on the seventeenth postoperative day afebrile and eating a normal diet He has done very well since and a subsequent gastrointestinal series has revealed no abnormality

This case demonstrates several interesting points

1 The esophagus apparently ruptured in this patient as he yawned and stretched in spite of a perfectly benign past history and the fact that there was no history of nausea or vomiting immediately antedating the rupture

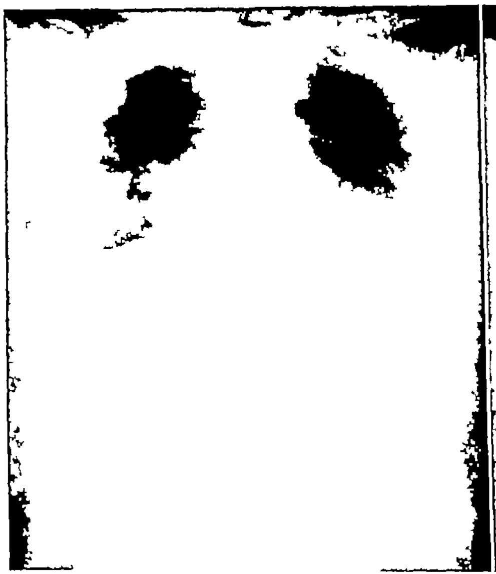


Fig 3

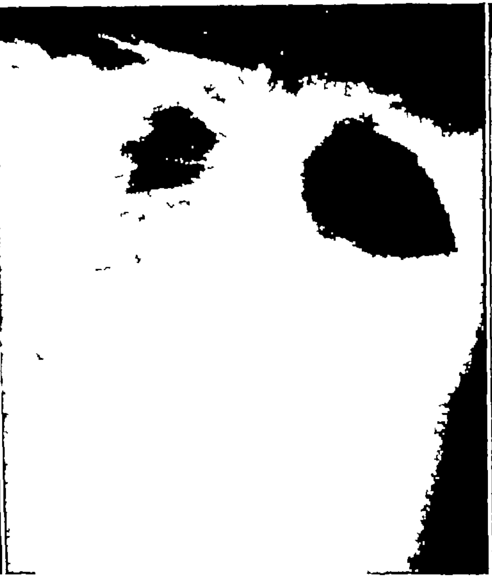


Fig 4

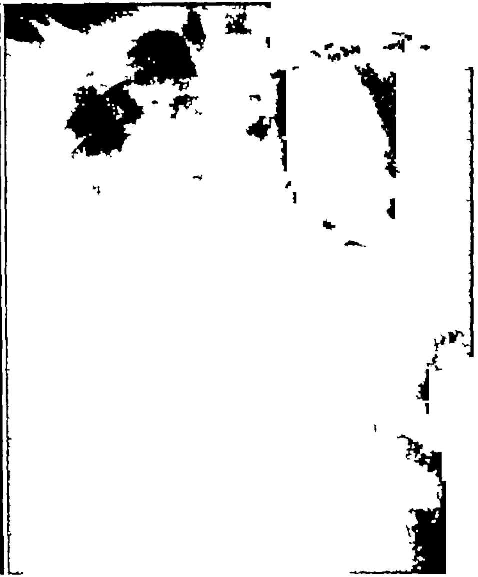


Fig 5

Fig 3.—Case 3 (R S) Admission film which shows left pleural fluid and slight mediastinal shift to the right.

Fig 4.—Case 3 (R S) X-ray of chest which demonstrates a left tension hydropneumothorax with more mediastinal shift to the right.

Fig 5.—Case 3 (R S) Left anterior oblique view of the chest after a Lipiodol swallow which demonstrates a left hydropneumothorax plus the presence of dye above the diaphragm and questionably below the diaphragm

2 He presented a shocklike picture and a story fairly consistent with a myocardial infarct, which was the initial diagnosis

3 With the development of the left pleural fluid and, eventually, a left tension hydropneumothorax the proper diagnosis was entertained and confirmed by a Lipiodol swallow

4 The esophagus was closed successfully about eighteen hours after it was ruptured

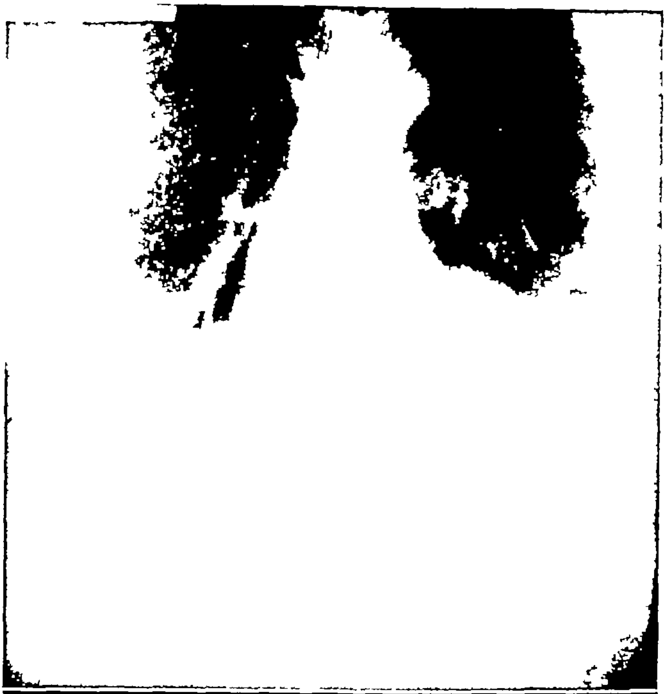
5 He demonstrated some hemoconcentration and as did the first patient, he had a much more stable and normal blood pressure after the mediastinum and pleura were cleared of gastric contents

CASE 4—S R, a 75 year old retired grocer, entered the hospital at 9 00 P M Jan 18, 1955, with a chief complaint of precordial and left chest pain of about thirty six hours' duration

Present Illness—This man had always been well but noted on the morning of the day before admission a rather sudden onset of precordial pain and some dyspnea He worked most of that day, ate three meals but his pain persisted and became worse It bothered him so much the night before admission that he was unable to sleep On the day of admission he had his usual breakfast of bacon and eggs toast, and coffee but began to feel weak The pain and dyspnea continued to increase At lunch time he lost his appetite and complained of some "gas" His wife gave him some baking soda which made him cough and vomit violently Immediately after his vomiting he broke out in a cold sweat became very pale, and complained of a sudden increase in pain He also became weaker and more dyspneic His local doctor was called to see him and noted that the pain in the precordium and left chest was radiating for the first time down the left arm He gave him an analgesic for his pain and sent him to the hospital where he was admitted to one of the general surgical services On the basis of his history it was initially thought that he had a perforated duodenal ulcer but subsequent x rays revealed mediastinal emphysema and fluid levels behind the heart (Fig 6) Subcutaneous emphysema in the supraclavicular fossa was noted on physical examination The diagnosis was therefore thought more likely to be a ruptured esophagus and the patient was transferred to the thoracic service three hours after admission He was given oxygen, and large doses of antibiotics His pain continued on into the morning and his blood pressure remained in the range of about 80/60, pulse 100, respirations 46 He was slightly cyanotic, orthopneic, and was thought to be too ill for operation He was treated with Levin tube decompression of the upper gastrointestinal tract, plus sedation A Lipiodol swallow was not satisfactory and therefore the x ray department gave the patient some thin barium (Fig 7) This demonstrated the esophageal leak and the lower mediastinal collection In any event, after much delay the patient was finally operated upon about twenty five hours after the rupture of the esophagus had occurred

A left thoracotomy was done A considerable amount of brownish red material was removed from the left pleural space The left lower lobe was adherent to the lower lateral surface of the mediastinum but as soon as the mediastinum was opened a large amount of fluid and old food gushed forth The patient's blood pressure, which had been in the range of about 70/50 came up to about 100/65 and remained in that range until after the operation A typical tear of the anterolateral surface of the lower end of the esophagus measuring 2 to 3 cm in length was found (Fig 8) The esophagus appeared normal grossly except for slight reddening of the mucosa Palpation within the lumen revealed no evidence of tumor foreign body, hiatus hernia ulcer, or other abnormalities The esophagus was then closed in 2 layers with interrupted No 4 0 silk sutures The mediastinum was debrided and the pleural space and mediastinum lavaged with a large quantity of saline A thoracotomy drainage tube was inserted and the chest closed An electrocardiogram was made immediately after operation because the history was also

Fig 6



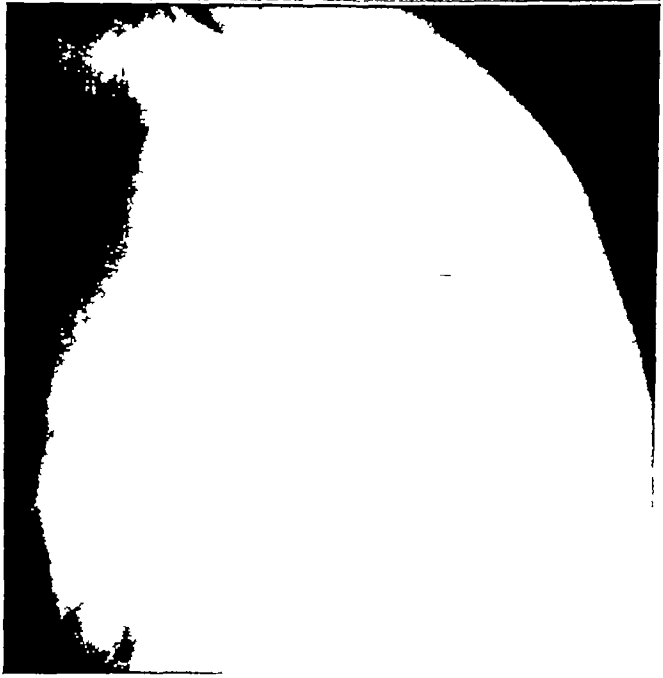


Fig 7

Fig 6.—Case 4 (S R) Admission x ray of chest shows bilateral pleural fluid A fluid level behind the heart and mediastinal emphysema are demonstrated

Fig 7.—Case 4 (S R) Left lateral chest film made shortly after admission shows mediastinal emphysema and a fluid level in the lower mediastinum behind the heart.

suggestive of a myocardial infarct This had been ordered before the operation but was not done, unfortunately It showed a myocardial infarct of perhaps thirty six hours' duration

Postoperatively the patient did well for about an hour and a half and then had a sudden drop of the blood pressure to 60/40 After the postoperative fall of blood pressure it was thought that he might have had a second myocardial infarct or progression of the first one Therefore he was kept on large amounts of oxygen sedation Levophed and digitalis The pressure was maintained in the range of about 100 mm of Hg systolic by the use of Levophed Initially he required a rather rapid drip of Levophed but his re quirements for the maintenance of that blood pressure diminished About eighteen hours after operation he began putting out urine The cardiovascular system seemed to be stabilizing by about the fourth postoperative day In the afternoon of the fourth day, he became rather excited and disoriented climbed out of bed, dislodged the intravenous needle and finally had to be restrained and put under heavy sedation After this violent exertion the blood pressure fell again to 60/40 and in spite of all efforts to resuscitate him he died on the fifth postoperative day An electrocardiogram on the fourth post operative day showed what appeared to be a second myocardial infarct

Fig 8 —Case 4 (S R) A barium swallow demonstrates a mediastinal collection communicating with the esophagus above the diaphragm The left insert demonstrates better the air fluid level in the mediastinum communicating with the lumen of the lower esophagus

Post mortem examination revealed a recent thrombosis of the right coronary artery as well as a recent myocardial infarction of three or four days duration which involved the right and left posterior ventricular walls and posterior septum There was a repaired perforation of the lower end of the esophagus which seemed to be healing (Fig 9) The esophagus was otherwise not remarkable The lungs showed some evidence of pulmonary congestion and edema The post mortem was limited to the chest and therefore these were the only findings available

This case again demonstrates the problems common to this disease

1 The local physician who first saw the patient apparently thought that he had a myocardial infarct which indeed was correct

2 The surgical service first thought that he had a perforated duodenal ulcer but very quickly revised their opinion to the proper diagnosis, namely, a ruptured esophagus In spite of this, there was too much delay in making the proper diagnosis and operating on this patient The reason for this seemed to be that even though there were fluid levels in the mediastinum behind the heart and evidence of mediastinal and supraclavicular emphysema the Lipiodol study was not satisfactory and the patient was given barium to prove the esophageal leak He was also a man of 75 years in very poor condition for operation but in spite of this he should have had earlier operation There was a delay of twenty-five hours from the time of rupture until closure of the esophageal tear was made

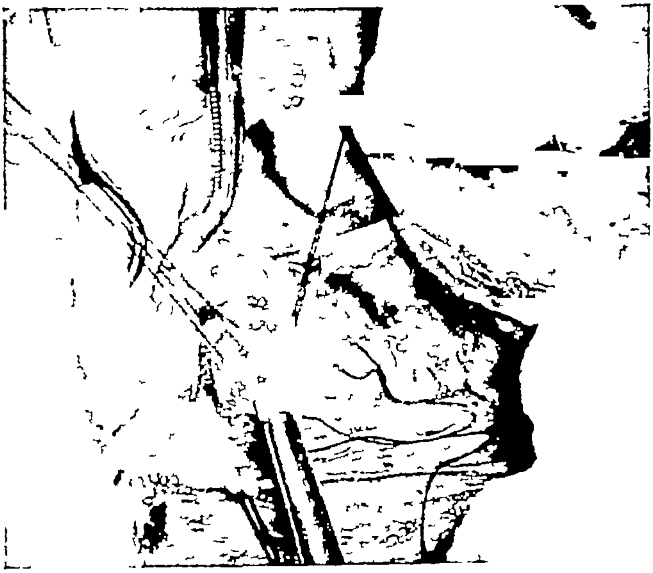


Fig 9 —Case 4 (S R.) View of the operative field which demonstrates the pouting mucosa of the esophagus at the point of rupture The diaphragm is retracted to the left toward the patient's feet for better visualization

3 He also demonstrated the rise in blood pressure after decompression of the mediastinum and pleural space

Discussion

The term "spontaneous" rupture of the esophagus is perhaps not a very accurate one Three of these 4 cases had esophageal rupture associated with severe vomiting, the fourth with yawning and stretching It would appear that a sudden increase in intra-abdominal and therefore intragastric pressure was a basic factor in 3 cases

Wangensteen[14] has suggested that esophagitis usually due to regurgitation of gastric contents into the lower esophagus is the important etiological agent—an opinion based primarily on experimental studies in dogs. In spite of this interesting experimental study, it would appear that the majority of cases of "spontaneous" rupture of the esophagus in human beings occur in normal esophagi as in these 4 cases. In my experience and in a brief perusal of the literature, it would appear that "spontaneous" perforation of the esophagus in patients with known esophagitis is a most unusual occurrence.

The diagnosis is usually easy to make. In not one of the 4 cases presented was the initial diagnosis correct. Severe pain in the anterior and posterior chest, a shocklike picture preceded by violent vomiting or effort is very suggestive of rupture of the esophagus. The presence of supraclavicular and mediastinal emphysema plus fluid or fluid and air in either pleural space is almost diagnostic. A Lipiodol swallow more frequently than not demonstrates the leak in the esophagus. Fluid levels behind the heart shadow or elsewhere in the mediastinum are commonly seen.

Treatment in the first thirty-six to forty-eight hours is surgical closure of the tear with interrupted fine silk sutures and adequate drainage of the mediastinum and pleural space. The sooner the closure is carried out, the better. Many of these patients present a picture of shock and should be treated for it. One of the essentials of early treatment should be to rid the pleural space of any fluid and air by means of a closed thoracotomy drainage if there is any unavoidable delay in proper closure of the esophageal tear. It is quite striking how well these patients tolerate surgical closure of the esophagus and how their shocklike picture is relieved once the pleural space and mediastinum are rid of the highly irritating foreign material which is often present and under considerable pressure. Massive antibiotic therapy and rapid re-expansion of the lung on the affected side are essential in avoiding late septic complications. Cases seen thirty-six to forty-eight or more hours after rupture should be treated by pleural and mediastinal drainage. In addition, a feeding jejunostomy is important for alimentation over the prolonged period of recovery.

SUMMARY

Four cases of so-called "spontaneous" rupture of the esophagus are presented. In all four patients the initial diagnosis was incorrect. The delays from the time of rupture until operation varied from twelve hours to eight days. Three cases were treated by primary closure of the esophageal tear with two survivals. The third patient, 75 years old, died on the fifth postoperative day of a second myocardial infarct. The fourth patient, 69 years old, in whom pleural drainage was instituted eight days after the rupture occurred, died three weeks later from massive hemorrhage and perforation of a duodenal ulcer.

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DISCUSSION

DR DEWITT C DAUGHTY, Miami, Fla—We have had the misfortune of seeing 6 patients with spontaneous rupture of the esophagus, in all of whom the esophagus was otherwise entirely normal and there was no evidence of other disease All had vomited at the time of onset of symptoms Four of them died because the diagnosis was not made until forty two or more hours had elapsed. Three were thought to have had perforated peptic ulcers because of the sudden onset of abdominal pain, rigidity, and shocklike state Two had the upper abdomen explored and both were noted to have air bubbles in the upper abdominal retroperitoneal space The true significance was not attached to this important finding One of them survived after the esophageal perforation was discovered and sutured twenty four hours after abdominal exploration The other died seventy two hours later and twelve hours after empyema drainage One survived after drainage of a complicating empyema ten days after onset

The diagnosis does not seem to be difficult to make if it is suspected It may be confused with coronary occlusion, peptic ulcer and, in 2 or 3 of our cases, it was called dissecting aneurysm

Rupture of the esophagus in all our cases was at the esophagogastric junction The lower mediastinal structures are bathed with gastric contents which produced a great amount of necrosis and sloughing of exposed tissue

DR WILLIAM K. SWANN, Knoxville, Tenn—We suspect that many instances of spontaneous rupture of the esophagus are unrecognized, and that this disease entity is a not uncommon medical emergency

We have encountered 4 proved cases of spontaneous rupture of the esophagus, in one medical community, in the brief space of two years

All 4 of these patients were sent to the hospital with a diagnosis of myocardial infarction In only 1 instance was surgical consultation sought It was not possible to err in this patient's diagnosis, inasmuch as he had agonizing, unremitting chest pain beginning after vomiting, subcutaneous emphysema was palpable in the neck, and the chest x ray revealed a small effusion at the left base Prompt surgical treatment resulted in uneventful recovery

The other 3 patients, and we emphasize these patients particularly, were believed to be suffering from coronary occlusion a surgical consultation was not even sought, and the true nature of the condition was not suspected until the autopsy was performed. Had there been no post mortem examination, death certificates in all these cases would have listed heart disease as the cause of death

We too have recently had occasion to review the literature relating to spontaneous esophageal rupture and we were impressed by the fact that the better papers and reviews had appeared in surgical and surgical specialty journals It would appear that their message has failed for the most part to reach the physician who must initially see evaluate and treat the patient with severe, agonizing chest pain

DR JOSEPH LUCIDO St Louis, Mo—We, also think that spontaneous rupture of the esophagus occurs probably more commonly than has been thought in the past and for that reason I would like to mention 5 cases Dr James L Mudd and I have had 4 cases in our own private practice All have occurred after severe episodes of vomiting In 3 patients the esophagus ruptured into the left pleural cavity Exploratory operations were performed on all three and the ruptures repaired. Two survived the third patient died. He was not operated on until approximately seven days after the rupture had occurred The fourth patient was a woman whose esophagus ruptured into the right pleural cavity and exploration was not done because she was in extremis when one of us was consulted. The fifth case was proved at autopsy This individual had an abdominal operation on the erroneous diagnosis of a ruptured peptic ulcer of the duodenum

DR ROY KLEPSER Washington D C—I have had 3 cases of ruptured esophagus successfully operated upon all of which were diagnosed by a swallow of iodized oil given to the patient by an astute radiologist These were all brought in as patients with ruptured peptic ulcers with negative abdominal x rays and the radiologist gave each one several cubic centimeters of iodized oil through an esophageal catheter If we are to diagnose this condition early enough for effective surgery, we must direct our educational efforts to the radiologists rather than to the general practitioners as it is a diagnosis which can be made by the roentgenologist long before mediastinitis occurs

One of these cases is noteworthy because there were 3 separate ruptures of the esophagus The patient was an alcoholic who had eaten a huge Thanksgiving dinner He said that he had vomited the entire meal in one vomiting This case was diagnosed several hours after the occurrence by means of iodized oil The esophagus was sutured and the patient did well for about two weeks then while on a soft diet the esophagus ruptured again It was resutured. At the first operation the mediastinum was filled with turkey dressing and at the second operation it was filled with onions At both operations the esophagus was thought to be rather rigid and indurated and a residual stenosis was feared but the mediastinum was too contaminated to warrant bringing up the stomach and doing an elective esophagogastrostomy One month later the esophagus again ruptured and at that time an esophagogastrostomy was done with resection of the lower end of the esophagus The patient is now well about three and a half months after his third operation for ruptured esophagus and is eating a regular diet without discomfort

DR S A MACKLER Chicago Ill—It was my good fortune to have on our house staff someone who was a photographic hobbyist I took advantage of his services to photograph as a motion picture 2 patients with spontaneous rupture of the esophagus I thought it would be of interest to show part of that film and the pathologic anatomy as it appear at the time of operation

The approach in this instance was through the bed of the resected eighth rib A large amount of free intrapleural gastric juice has already been evacuated and here the lung is being reflected from the aorta to disclose the inferior pulmonary ligament and the mediastinal pleura The inferior pulmonary ligament is now stretched and I think you can visualize the hole in the mediastinal pleura at its base This was eroded by the collection of gastric content in the mediastinum through which it evacuated itself into the pleural space This was previously mentioned The mediastinal pleura is now being opened to disclose the esophagus There is some digestion of the surface of the esophagus as a result of the action of the free gastric juice Note the longitudinal split in the esophagus in the region just above the diaphragmatic hiatus *The margins of the rupture are clean cut, as though an incision had been made* The lower angle of the wound is located just within *the diaphragmatic hiatus itself* You can see *some of the gastric* contents now spilling through the rupture The site and the longitudinal nature of the split *in the esophagus are characteristic of this condition*

DR WILLIAM W HEROY, Huntington, N Y—I rise to show two slides which I think are rather helpful in making an early diagnosis The first slide is a routine chest plate and the flat plate one gets on a patient coming in with this condition While you might suspect it, correct interpretation of this is certainly difficult The only reason I show this is that *with a more heavily exposed type of picture, leveled at the diaphragm* (slide), it is fairly obvious that there was a tremendous admixture of mucus and air in *the extrapleural space which had not broken into the pleura I think if you remember* to take a Bucky film when you suspect this condition, perhaps before you give Lipiodol, it might be of some help in making an early diagnosis

DR J D FRYFOGLE, Detroit, Mich —Since spontaneous ruptures of the esophagus, especially those of the nonalcoholic type, are rare, I thought I would report the progress of the little girl whose case I presented two years ago Her esophagus perforated into the right chest, the cause, an obstructive web at the esophagogastric junction I opened the baby's chest twelve hours after birth on a wrong diagnosis I thought I was dealing with a ruptured thoracic stomach With the pathology exposed, a catheter passed through *the nose, passed the hole in the esophagus, hit the obstruction* and doubled back on itself to come out the rupture site This esophageal hole was enlarged longitudinally (which *I now believe was a technical error), the obstructing web was resected,* and the esophagus closed

Here is a film taken when the patient was 3 years of age *The resultant stricture* is not as gross as the film would indicate, for a No 16 dilator passes with ease I have had one problem with this child for which I intend to spank *her as soon as she* is old enough to understand From the time she could crawl she would eat paper, and while food passed very well, the paper wads needed endoscopic removal As proof of the food' passage, here is a picture of the plump 3 year old child taken one week ago

DR LAURENCE H RUBENSTEIN, Chicago, Ill —Another clinical diagnostic test might be mentioned, namely, the use of the sense of smell I had an experience with a case where again the initial diagnosis was incorrect He was a seriously ill 36 year old *man with pleural effusion which was diagnosed as fulminating* pneumonitis with effusion There was no mediastinal emphysema The resident placed a needle in the chest and withdrew *grayish brown thick fluid which when smelled had a gastric odor* The diagnosis was made of ruptured esophagus with gastric contents in the left chest Surgical repair *was satisfactorily carried out twenty eight hours after the initial onset of symptoms*

DR L D MAC LEAN, Minneapolis, Minn —I would like to emphasize the importance of the acid peptic factor in this disease entity It has been routinely possible to produce esophageal rupture in experimental animals, dogs, and rats, by ligation of the pylorus, a situation which can be corrected by removal of the acid producing portion of the stomach It has also been noticed clinically that vomiting is a very common forerunner of this difficulty Perhaps the cases reported by Cushing are of this origin Duodenal ulcer is not an uncommon finding in this disease also, whereas if one attempts to produce a lesion in the esophagus by pressure means alone, it requires approximately 800 mm Hg to rupture the esophagus in contrast to 80 mm Hg for the stomach

DR EMIL A NACLERIO, New York, N Y —During the past eighteen months, my experiences with 4 *proved cases of spontaneous rupture of the esophagus has afforded* me the opportunity to make three pertinent observations

1 Regardless of the stage of the disease in which the patient was seen, a Lipiodol swallow revealed extravasation of the oil into the mediastinum or pleural cavity

This patient had a Lipiodol swallow on the twelfth day following esophageal rupture

2 In 2 patients, both thought to have had an acute ruptured ulcer, x rays were taken on admission for visualization of air under the right hemidiaphragm Both of these films revealed a left sided localized mediastinal emphysema taking the form of a "V," which I call the V sign This V sign is caused by the air which elevates the diaphragmatic and mediastinal pleurae, and manifests itself early Later, pleural effusion results due to the reflux of gastric juice, and the V sign is no longer evident This sign should be looked for whenever an x ray of the upper abdomen or chest is taken for any acute abdominal or thoracic emergency

3 The recovery of ingested dye from the pleural cavity by thoracentesis is also diagnostic of an esophageal leak This test, however, should not be relied upon for diagnosis since in some cases it will not be recovered despite the presence of rupture of the esophagus

At surgery, numerous loculations were found The pocket in the immediate rupture site contained the methylene blue while there was straw colored pleural effusion present elsewhere

DR GEORGE W B STARKEY (Closing) —It is obvious from all this discussion that "spontaneous" rupture of the esophagus is not an uncommon problem but that its diagnosis is frequently missed There are several points which have been raised on which I would like to comment One of the discussers I believe mentioned using 2 to 3 c c of Lipiodol via a catheter in the esophagus to demonstrate the leak I believe that 10 to 20 c c of Lipiodol taken in one swallow will increase the chances of finding the esophageal rent

The use of a swallow of methylene blue has not proved very satisfactory in my hands I think the reason for this is that the chest fluid is usually a dirty brown and the addition of a little methylene blue introduced via the esophageal route will not shift the spectrum of the chest fluid appreciably

The question of there being an underlying peptic esophagitis in these cases of spontaneous rupture of the esophagus has been raised Wangensteen and his group feel, I believe that this is usually the case Their experimental studies in dogs certainly demonstrated that the amounts of hydrostatic pressure necessary to rupture the lower esophagus was greatly reduced in that group of dogs with peptic esophagitis However in the clinical cases based on history, esophagoscopy, barium swallow, operation observation, and post mortem material, the presence of a coexisting esophagitis seems quite rare

I would like to thank all the discussants of this paper

ONE-STAGE PHARYNGO-ESOPHAGEAL DIVERTICULECTOMY

J D Mortensen, M D (by invitation),* O Theron Clagett, M D,**
Herbert W Schmidt, M D,*** and Howard K Gray, M D**
Rochester, Minn

ALTHOUGH surgical excision has been accepted treatment for most pharyngo esophageal diverticula, for more than 40 years surgeons have debated the relative merits and demerits of the one-stage versus the two stage operation for this lesion[1, 2] At present there is no unanimity of opinion as to the procedure of choice The most recent and authoritative reports are those of Lahey,[3] and Lahey and Warren,[4] who strongly defended the two stage operation and challenged advocates of the one-stage procedure to demonstrate comparable results Most surgeons today apparently favor the one-stage operation even though there has been no report in medical literature describing a comparable series of patients who underwent the one stage operation with mortality, morbidity, and cure rates equivalent to the most commendable results achieved by Lahey using the two-stage operation

METHODS OF STUDY

We have reviewed all cases in which one-stage pharyngo esophageal diverticulectomy was performed at the Mayo Clinic during the ten-year period Jan 1, 1944, through Dec 31, 1953 Our series consists of 339 such cases During this period there were no instances in which two stage diverticulectomy was done We have reviewed the Clinic and Hospital records with particular attention to the preoperative clinical findings and preparation for operation, operative findings, and technique of operation, postoperative management and course, duration of stay in the hospital, and duration of postoperative observation before the patient was dismissed from medical care

FINDINGS

Mortality—Three of the 339 patients died during hospitalization, giving a hospital mortality rate of 0 9 per cent One patient had aspirated regurgitated diverticular contents preoperatively which had produced aspiration pneumonitis He was operated on as a semiemergency because the large pharyngo esophageal diverticulum was completely obstructing the esophagus He died of pneumonia on the fourth postoperative day The second death occurred suddenly from massive pulmonary embolism, the patient had otherwise ex

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Read at the Thirty-fifth annual meeting of The American Association for Thoracic Surgery at Atlantic City New Jersey April 24 to 26 1955

The Mayo Foundation Rochester Minn is a part of the Graduate School of the University of Minnesota

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***Section of Medicine Mayo Clinic and Mayo Foundation Rochester Minn perienced a normal postoperative course. The third death occurred eight hours postoperatively from sudden massive hemorrhage from the superior thyroid artery.

Early Postoperative Complications.—Postoperative drainage of salivary juice with or without food through the drained operative incision occurred in 11 patients (3.2 per cent). These temporary pharyngo-esophageal-cutaneous fistulas all closed spontaneously during the immediate postoperative hospitalization. None were permanent and none required further surgical intervention. Thus persistent pharyngo-esophageal-cutaneous fistula did not occur in any of the 339 patients.

Frank infection, characterized by fever and purulent drainage, developed in 6 patients (1.8 per cent). In 3 of these the infection was classified as suppurating mediastinitis while in the other 3 it was considered a simple wound infection. In all 6 patients the site of infection had been adequately drained by Penrose rubber drains inserted at the time of operation. These drains were left in place until evidence of infection had subsided and no further treatment other than systemic administration of antibiotics was required. In all cases the infection subsided without additional complications and a satisfactory result was obtained in each case.

Four patients (1.2 per cent) sustained unilateral vocal cord paralysis, evidently from trauma to a recurrent laryngeal nerve. In 3 patients the paralysis was permanent and in one it disappeared spontaneously after seven months. None of these 4 patients required treatment for the vocal cord paralysis.

Morbidity.—The average period of hospitalization for all patients in this series was 9.1 days. Many were dismissed from the hospital on the fourth postoperative day. The longest period of hospitalization, thirty-two days, was that of a patient who had postoperative salivary drainage from the operative site for eighteen days and who then underwent inguinal herniorrhaphy while he was still in the hospital. The average period of observation or medical supervision after the patient left the hospital was 4.5 days. Thus for the entire group of patients the average time between operation and complete dismissal from medical care was 13.6 days. In recent years this time has been decreased considerably. Of 72 patients operated on in the last three years covered by the study the average period of hospitalization was 6.4 days and the average period of observation after dismissal from the hospital was 1.7 days. Thus at present the average patient undergoing one-stage pharyngo-esophageal diverticulectomy is completely dismissed from medical care and permitted to return to his home approximately a week after operation.

Late Results.—In the present study we have not endeavored to investigate accurately the long-term definitive results of one-stage pharyngo-esophageal diverticulectomy. It is not the purpose of this report to claim that the end results following the one-stage operation are appreciably superior to those following the two-stage operation. For obvious reasons it is difficult if not impossible to accumulate data which could be used satisfactorily for making such a comparison. However, it seems reasonable to assume that, when it is possible to complete a procedure in a surgical field that is devoid of marked inflammatory reaction, there is increased likelihood that a satisfactory result will be obtained

Although all the patients in our series were operated on one or more years before the study was made, we have acceptable follow up information on only 154 of them One hundred forty-six of these patients (94 8 per cent) were found to be completely asymptomatic so far as the esophagus was concerned The 8 patients who had symptoms after one-stage pharyngo-esophageal diverticulectomy included 3 patients with symptomatic recurrence of the diverticulum, 2 with postoperative constrictions at the operative site 2 with unexplained dysphagia (both appeared normal roentgenologically and esophagoscopically), and 1 with persistent hoarseness due to unilateral vocal cord paralysis The 3 patients with symptomatic recurrence and the 2 patients with postoperative constriction were all successfully treated by peroral esophageal dilations

TECHNICAL CONSIDERATIONS

Since the operations in our series have been done by seven different surgeons, the technical details of operation and of preoperative and postoperative management have varied considerably Most (85 per cent) of the patients underwent preoperative peroral esophageal dilation over a previously swallowed thread, although currently this procedure is being done less frequently Ninety-four per cent of the operations were done under cervical block type of regional anesthesia At present, the use of general anesthesia with tracheal intubation seems to be increasing in favor

All diverticula in the midline or projecting to the left were approached through a left cervical incision, while those projecting to the right (79 cases or 23 per cent) were approached from the right side An adequate longitudinal incision along the anterior border of the sternocleidomastoid muscle was utilized routinely After the diverticulum had been exposed, it was mobilized and its neck dissected free When the point of exit of the diverticulum through the muscle fibers composing the wall of the pharynx and esophagus was accurately identified, the diverticulum was amputated at this point

Methods of closure of the defect in the wall of the pharynx and esophagus have varied One of three procedures has been used most commonly (1) multiple transfixion ligation with chromic catgut and invagination of the stump, (2) the placing of interrupted fine silk sutures in the mucosa in such a manner that the knots will be on the inside, with a second row of fine silk or catgut sutures in the muscle layer, and (3) the placing of continuous fine catgut sutures in the mucosa with a second row of either silk or catgut in the muscularis Some surgeons prefer a specially designed curved clamp to hold the neck of the sac while others do not use the clamp We could not demonstrate significant differences in results achieved with these various methods of closure

In all cases, the operative site was drained by leaving one or two small rubber Penrose drains in the wound If two drains were used, one was directed down into the mediastinum while the end of the other was left in close proximity to the suture line in the esophageal wall. A gauze pack was also inserted in 83 cases (25 per cent) in the early part of the period covered by this study but the frequency with which the pack was used decreased markedly in later years. In about two-thirds of the cases some type of antibiotic or chemotherapeutic agent was instilled into the wound before it was closed but this, too, is rarely done now. All patients routinely received antibiotics systemically for the first few days postoperatively. A Levin tube was used postoperatively in only 9 cases (2.7 per cent) in the entire series. Ingestion of food and fluids was not permitted in the immediate postoperative period during which the patient was maintained on intravenously administered fluids. The duration of this postoperative fast was usually forty-eight to seventy-two hours although it was extended if there was increased drainage from the wound when sips of water were taken orally. The patients were permitted to get out of bed on the day following operation and were ambulatory thereafter. Liquid diet was continued for twenty-four to forty-eight hours following which a mechanically soft diet was prescribed for two or three weeks. The diet was not restricted beyond this time.

COMMENT

We fully appreciate the excellent results achieved by Lahey using the two-stage operation for excision of pharyngo-esophageal diverticulum. However, since equally good immediate results follow the use of the one-stage procedure (Table I), we believe the one-stage pharyngo-esophageal diverticu-

TABLE I. COMPARISON OF RESULTS OF THE ONE-STAGE OPERATION WITH RESULTS OF THE TWO-STAGE OPERATION FOR EXCISION OF PHARYNGO-ESOPHAGEAL DIVERTICULUM

	ONE-STAGE OPERATION		TWO-STAGE OPERATION (LAHEY)	
	CASES	PER CENT	CASES	PER CENT
Cases reported	339	100	365	100
Operative (hospital) deaths	3	0.9	2	0.6
Postoperative complications				
Drainage of saliva, food (temporary)	11	3.2	"Limited number"	
Persistent pharyngo-esophageal cutaneous fistula	0	0	2	0.6
Infection	6	1.8	Not stated	
Vocal cord paralysis	4	1.2	Not stated	
Period of convalescence				
Average hospitalization, days	9.1 (6.4)*		14-19 minimum	
Average posthospitalization observation before complete dismissal, days	4.7 (1.7)*		Not stated	
Average total time from operation to complete dismissal from medical care, days	13.6 (8.1)*		Not stated but 14-19 minimum	

*Calculated for 72 patients operated on during the last 7 years.

lectomy to be the procedure of choice for most, if not all, patients with this lesion. We believe that the simplest surgical procedure requiring the shortest period of hospitalization, the shortest period of postoperative convalescence, and the least emotional and financial trauma to the patient should be selected if it produces equally good rates of cure without increasing the morbidity and mortality rates.

SUMMARY

From our study of a large group of cases in which one stage pharyngo esophageal diverticulectomy was performed, we are able to report operative mortality and morbidity rates that are as good as, and in some instances better than, the best rates reported following the two-stage operation for excision of pharyngo-esophageal diverticulum. Furthermore, the period of hospitalization and the period of observation after leaving the hospital were significantly less when the one-stage procedure was used. When these results are considered, together with the economic and emotional advantages to the patient who undergoes only one operation instead of two, we believe that the one-stage procedure for excision of pharyngo esophageal diverticulum is preferable to the two-stage procedure.

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DISCUSSION

DR. HERBERT C. MAIER, New York, N. Y.—I fully agree about the advantages of the one stage operation for pharyngo esophageal diverticulum. I rise to discuss a situation in which not only was a one stage operation indicated, but where it should have been done as an emergency.

I am referring to an unfortunate situation where a pharyngo esophageal diverticulum had been perforated endoscopically. I saw this patient about four hours after the endoscopy because of the development of emphysema in the neck. Although we considered the possible advisability of immediately resecting the previously demonstrated diverticulum, we did not do that but merely drained the cervical region as one may do for endoscopic injury to the cervical esophagus. A film taken one week later showed that Lipiodol was extravasating from the esophagus and had collected in the mediastinum, indicating the need for a secondary posterior mediastinotomy.

A film demonstrated why one should in this sort of situation treat the patient by immediate definitive diverticulectomy. One could see the diverticulum and the tiny but very persistent fistula from the dependent portion of the diverticulum leading into the mediastinal abscess. If we had given this patient Lipiodol before we did the original emergency operation, I am sure we would have proceeded immediately to diverticulectomy, since the roentgen demonstration of diverticular perforation would have suggested the improbability of spontaneous closure of a perforation so located. There was as yet no inflammatory process in the neck which would have contraindicated this procedure. At this later stage diverticulectomy was done, but much valuable time had been lost.

A roentgen examination is important in making certain that one is not dealing with an unusual type of diverticulum in this area. Although this particular diverticulum was at the same level as the usual pharyngo-esophageal type it was truly a rare lateral esophageal diverticulum one which protruded from the anterolateral aspect of the upper esophagus From the original films which did not include a true anteroposterior projection we were thinking of operating from the left side which would have been a most unsatisfactory approach in this case

DR J D FRYFOGLE, Detroit Mich —I should like to discuss Dr Gray's paper in response to Dr Lahey's challenge and defend the one-stage procedure In so doing I would like to add 15 cases of my own that have not been previously reported Fourteen were men and there was one woman the ages were from 48 to 83 The predominant symptom was dysphagia Preoperatively the nutritional deficiencies were corrected the patients were esophagoscoped so that the mouth of the sac and the normal esophageal lumen could be compared Bacteriologic studies of the sac contents were made and the patients were given oral drops of Terramycin.

I show this only because it is the most beautiful picture of a diverticulum that I have ever seen and the only one I have seen where the pharynx and the esophagus are so beautifully outlined together I believe and I am sure you believe in Dr King's theory of an acquired development of these diverticula He suggests in his monograph that on swallowing there is gradual enlargement of the sac and the prevention of a ridge following repair is important For this reason I wish to present two technical points in the one-stage procedure that have proved to be helpful.

The realignment of the muscularis of the esophagus obviously can be only in the plane of the constrictor fibers However the realignment or the suture line could be made on the closed surface and swung in almost any direction The second problem that occurs is that we sometimes cut the sac on the bias To prevent the latter a Duval lung clamp is placed across the neck of the sac By cutting and sewing parallel to the clamp a flush straight line of closure is obtained No 4-0 silk is used for suture

The advantages of the method are that there is no suture ridge or dimple for the start of a new sac The two angle closure strengthens the posterior pharyngeal wall as cross grained plywood adds strength to its respective thickness

Our results in this series of 15 patients have been excellent There have been no deaths and no complications except a small salivary fistula in one which closed spontaneously in thirty six hours This group has been followed for three years and all the patients are still alive including the 83 year-old woman

DR C L JACKSON Philadelphia Pa —I am very glad to hear such an eloquent and authoritative voice raised in support of the one stage *operation* The Jackson Clinics have been fighting for this operation even long before the antibiotic era dating from the paper by Gaub and Jackson in *Surgery Gynecology & Obstetrics* away back in 1915[1] It has been the feeling of the Jackson Clinics that this operation was to be preferred to the two stage in the vast majority of cases I admit with Dr Gray that the argument is greatly strengthened in the past ten years by the development of antibiotic postoperative management We have now in press a report of a series of cases in which the operation was done by myself and my associate Dr Charles Norris In only two of these cases was a two stage operation done because of special indications There was no operative mortality in a series of 50 consecutive cases

DR HERBERT D ADAMS Boston Mass —I am sure that if Dr Lahey could have been present to discuss this paper he would have been greatly impressed and very much interested in the fine results in this series We must not forget however, that he devised the two-stage procedure prior to the era of antibiotics at which time opening the esophagus with its mixed organisms and flora of the mouth, carried a very high morbidity and mortality and it was for this same reason that esophageal resection at that time was a very hazardous procedure His results were so excellent with the two-stage procedure under these adverse conditions that he continued to favor this method all his life He and I had many discussions after the advent of antibiotics, and as I gained experience in safe esophageal surgery under antibiotic coverage, I began to resect diverticula in one stage, with uniformly good results as reported in this paper

There is only one type of patient in whom I would still prefer to use a two stage procedure, and these are the patients in a serious state of malnutrition associated with a large obstructing diverticulum A simple diverticulopexy will permit them to eat, and one can take as long as necessary, even months, to get them into a good nutritional state We have had several patients with serious coronary occlusions, in whom diverticulopexy alone was done, and normal eating and nutrition were maintained for the remainder of their lives The only other point of importance that occurs to me is that we are encountering more and more resistant organisms, and there may come a time when the two stage operation may perhaps again be necessary for the same reasons for which it was originally devised

DR JOHN M DORSEY, Evanston, Ill —I, too, have had such a case as Dr Maier has encountered, one of two

A mediastinal abscess arose from a perforated diverticulum, which we discovered after mediastinotomy failed to eliminate the abscess

My remarks are particularly directed toward the treatment of the recurrent diverticulum, for those of us who have had a patient with recurrence after either a one stage or perhaps two stage operation In my own experience, the mistake I made, to which I wish to call attention, is the too early re operation after recurrence I feel it is best to wait until the recurrence has been established, and the tissues have come back to a nearly normal state before attempting a second operation A further point—I have witnessed one of the factors of recurrence in the immediate postoperative period, and that, to my surprise, was due to a very marked straining from attempted emesis I am sure that this accounts for some early postoperative leaks, and even an indwelling Levin tube may fail to prevent it

DR HOWARD K. GRAY (Closing) —I certainly wish to thank the discussers for their comments I agree that at the present time Dr Lahey would probably utilize the one stage procedure It is quite possible that we may have to resort to the two stage procedure should the organisms involved in these cases become resistant, but up to now this apparently has not been necessary

With regard to Dr Maier's comment about the diverticulum pointing to the right, I might say that exploration of the diverticulum was done on the right side in approximately 25 per cent of the patients in this series We do not mean to indicate that all patients must be operated upon by the one stage procedure The general condition of the patient, particularly with relation to his nutritional stage, may dictate a more conservative procedure at first, but in our experience this has not been necessary in recent years, as has been stated in the paper

One final comment rarely, will one find a carcinoma in the pharyngo esophageal diverticulum I have had only one in my personal experience, but I believe that there have been two or three others seen in our institution If there is any suspicious filling defect in the diverticulum, as shown roentgenographically, the possibility of cancer must be considered

ENDOSCOPIC TREATMENT OF BRONCHIAL FISTULA

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SÃO PAULO, BRAZIL

THE endoscopic treatment of the bronchial stump fistula as a complication of excisional therapy for tuberculosis, as suggested by Overholt, has been performed on 14 patients. It is the purpose of this paper to describe in detail the endoscopic findings and the clinical evolution in such cases.

Case 1.—D. R., a 28 year old white woman. A left pneumonectomy for tuberculosis was performed on Oct. 28, 1949, followed by corrective thoracoplasty on Dec. 12, 1949. On July 6, 1950, a diagnosis of bronchopleural fistula was made. On the same day underwater drainage was begun. The patient's condition improved. On Jan. 23, 1951, a bronchoscopy was performed and a 5 mm. opening was observed in the bronchial suture, which was cauterized with 20 per cent sodium hydroxide and neutralized with acetic acid. The same process was repeated on February 12, when stimulation of the bronchial lumen closure was noted. Bronchoscopy was performed again on March 4, and this time the bronchial fistula was not seen. Bronchography twenty days later showed that the bronchial stump fistula was closed. The patient was discharged from the hospital on Feb. 28, 1952.

Case 2.—M. S., a 25 year old Negro man. An upper left lobectomy for tuberculosis was performed on Jan. 30, 1950. On February 2 diagnosis of bronchopleural fistula was made. Corrective thoracoplasty was performed on March 3. Bronchoscopy on Nov. 11, 1950, showed a 10 mm. opening in the bronchial suture. This opening was cauterized with 20 per cent sodium hydroxide and neutralized with acetic acid. Bronchoscopy on November 18 showed stimulation of the bronchial closure. During January 1951 there was no clinical signs of bronchial fistula, but bronchography on May 5 showed persistence of the fistula. Bronchoscopy and cauterization were performed on November 25 and December 12. Complete closure of the stump was seen. The patient died on Aug. 8, 1953, of cardiac failure.

Case 3.—M. J. O., a 38 year old white woman. A left pneumonectomy for tuberculosis was performed on March 3, 1953. On April 10 diagnosis of bronchial fistula was made by clinical findings. With bronchoscopy on April 13 a 4 mm. opening was observed in the bronchial stump. It was cauterized with 20 per cent sodium hydroxide and neutralized with acetic acid. Bronchoscopy and cauterization were done again on April 27, followed by reduction of the bronchial lumen. On April 29 intercostal underwater drainage was performed, followed by bronchoscopy and cauterization on May 5. The fistula was not seen. On May 16, open drainage of the hemithorax was done. A corrective thoracoplasty was performed on Aug. 20, by Dr. Botelho. The hemithorax was opened and the fistula was not seen. The patient was discharged from this hospital on July 4, 1954.

Case 4.—A. C. L., a 28 year old white woman. An anterior thoracoplasty, followed by cavity drainage and two stage posterior superior thoracoplasty had been performed in another hospital. In this service a right superior lobectomy for residual cavity and apical inferior segmentectomy were performed on April 24, 1953. Clinical diagnosis of bronchial fistula was made on April 27, followed by total opening of the suture of skin and muscular layers

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Hospital Miguel Pereira, Department of Surgery—Chief Surgeon, Gabriel Botelho.
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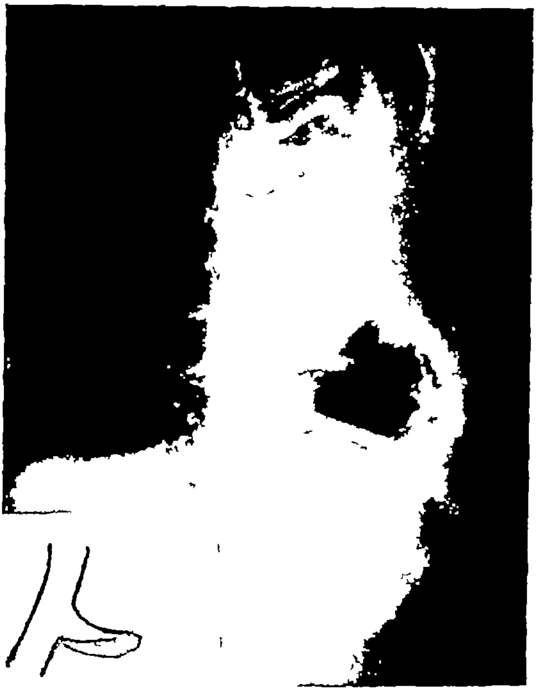

Fig. 1.—*Case 1.* Bronchography showing bronchial stump closed following treatment.

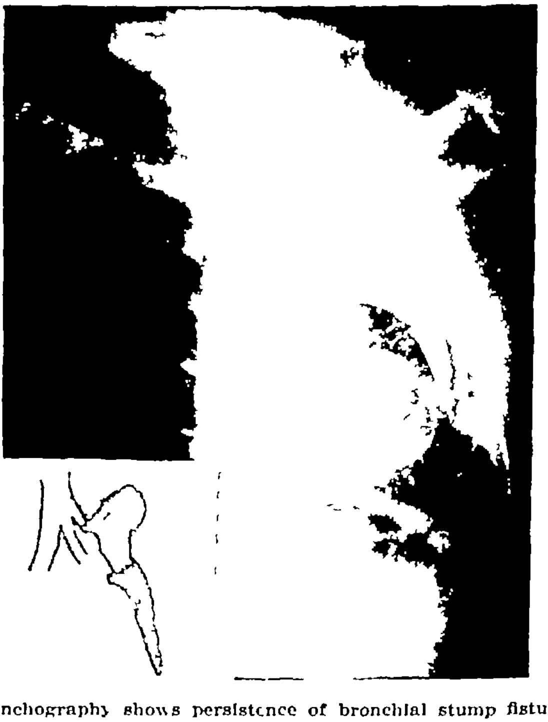

Fig. 2.—*Case 2.* Bronchography shows persistence of bronchial stump fistula after treatment.

Bronchoscopy on May 25 showed total opening of the bronchial stump which was cauterized. The patient's general condition improved in the next four months Another bronchoscopy (on October 27) showed a great reduction of the bronchial lumen Bronchoscopy was repeated on November 17, at which time the fistula was not seen. Bronchography on November 22 showed the fistula. On December 12, a thoracoplasty was performed by Dr Botelho, and the hemithorax was opened. A small fistula at the stump of the bronchus of the superior lobe was sutured with steel wire The patient was discharged from this hospital on March 3 1954

Case 5—A. S G, a 23 year old white woman. A right upper lobectomy and apical inferior segmentectomy for pulmonary tuberculosis was performed on March 3, 1953 There was no total pulmonary re-expansion in the postoperative period and there were aspirations of intrapleural fluid Bronchoscopy was performed on April 1, when a 3 mm opening of the bronchial stump was seen It was cauterized with sodium hydroxide and neutralized with acetic acid Bronchoscopy was repeated on May 25, showing the bronchial lumen reduced, and no fistula present There were no clinical signs of bronchial fistula Corrective thoracoplasty was performed on May 25 On March 18, 1954, a right inferior lobectomy was performed by Dr Botelho, and a small fistula was seen in the right superior bronchus stump and sutured with steel wire The patient is still under treatment

Case 6—H H a 17 year old part Japanese woman A left pneumonectomy for tuberculosis was performed on Oct 20 1950 On October 30, the patient developed a bronchial stump fistula On November 25, bronchoscopy showed the tracheobronchial tree full of secretions The patient was aspirated On bronchoscopy again on December 5 a 3 mm opening of the bronchial stump was seen and cauterized with 25 per cent silver nitrate Bronchoscopy was performed again on Feb 21 1952 and the fistula was not seen This was followed by cauterization of the bronchial stump with sodium hydroxide and neutralization with acetic acid This treatment was repeated on April 10 Bronchography on Feb 2, 1952 showed a very small fistula. Patient died on July 18 1952 of cor pulmonale

Case 7—A I S, a 24 year old white man A right pneumonectomy for tuberculosis was performed on Aug 14, 1953 The next day a bronchial fistula was apparent Corrective thoracoplasty with opening of the hemithorax and bronchial fistula closure with steel wire was performed on Oct 12 1953, by Dr Botelho The bronchial fistula reopened on the third postoperative day Bronchoscopy on October 23 showed a 2 mm. opening of the bronchial suture It was cauterized with 20 *per cent* sodium hydroxide and neutralized with acetic acid Open drainage was performed on October 25 and a bronchoscopy on November 16 did not show the fistula, but three bronchial sutures were visible Cauterization with sodium hydroxide and neutralization with acetic acid was done Bronchoscopy on November 1 showed no sutures and that the bronchial lumen was reduced. The patient was discharged from this hospital on Feb 10, 1954

Case 8—I N a 22 year old white man A left inferior lobectomy for tuberculosis was performed on Aug 17 1953 Corrective thoracoplasty and underwater drainage had been performed in another hospital Diagnosis of bronchial stump fistula was confirmed by bronchoscopy on November 1 and a 2 mm opening was seen and cauterized with sodium hydroxide and neutralized with acetic acid Bronchoscopy on November 17, showed the bronchial lumen reduced by cicatricial tissue and the fistula was not seen The patient recovered and was discharged from this hospital on Feb 10 1954

Case 9—L P R a 27 year old white man A right inferior lobectomy for tuberculosis was performed on Sept 9 1949 On October 1, clinical signs of bronchial stump fistula were evident Corrective thoracoplasty was performed on November 9 Bronchoscopy on April 7 1951 showed a 2 mm opening of the suture Cauterization and neutralization with acetic acid were done Bronchoscopy and cauterization were performed on April 21 and on May 5 No fistula was seen. The patient was cured and was discharged from this hospital on Jun 15 1951

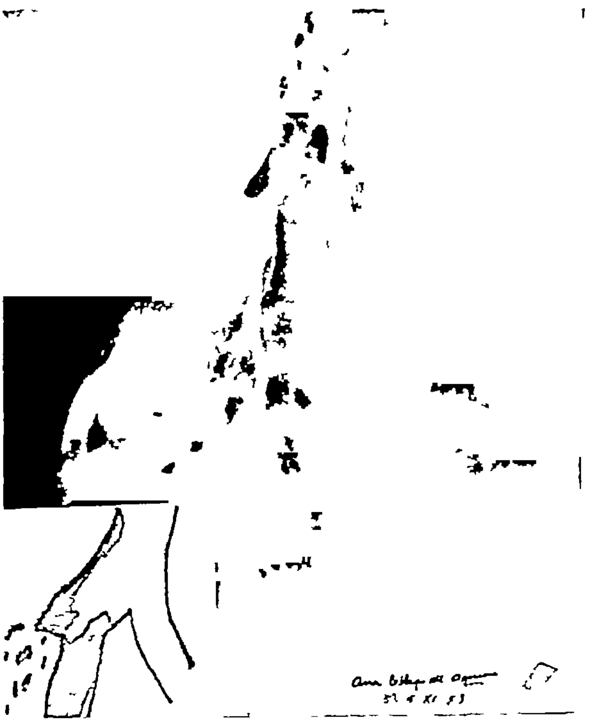

Fig 3.—*Case 4* Bronchography shows the bronchial stump fistula opened after treatment.

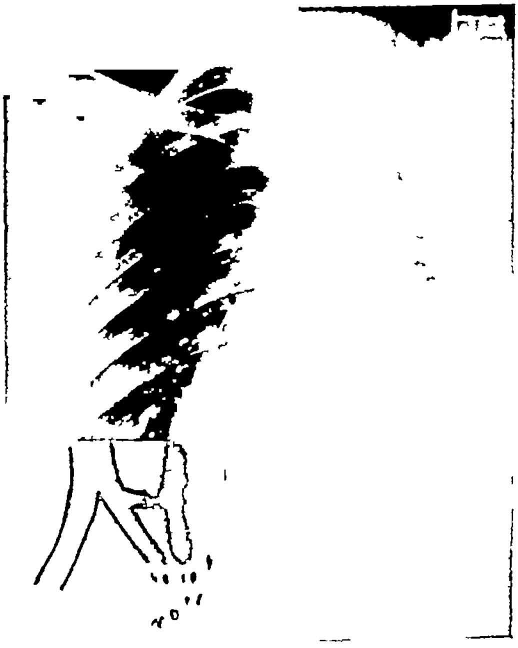

Fig 4.—*Case 5* Bronchography shows bronchial stump fistula opened after treatment

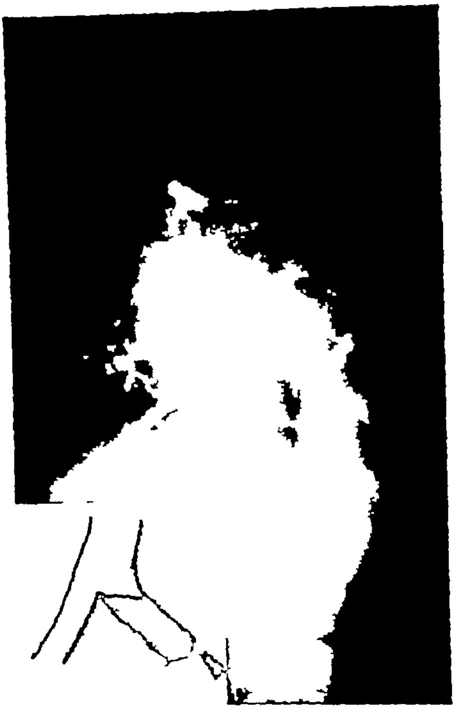

Fig 5 —*Case 6* Bronchography shows persistence of small bronchial stump fistula after treatment.

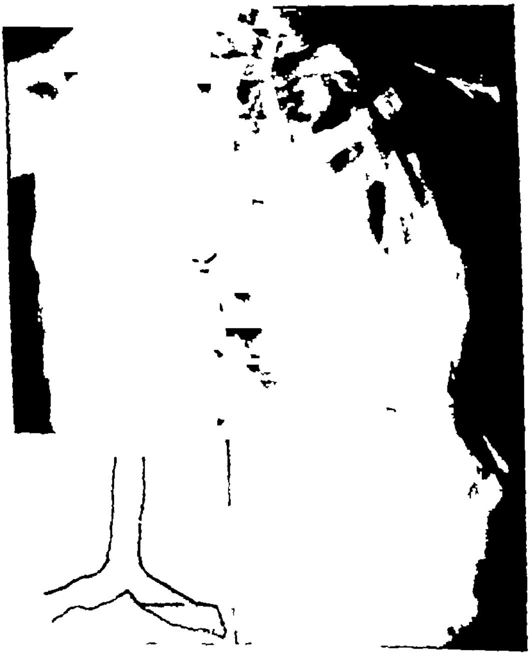

Fig 6 —*Case [illegible]* Bronchography shows closure of the bronchial stump fistula after treatment

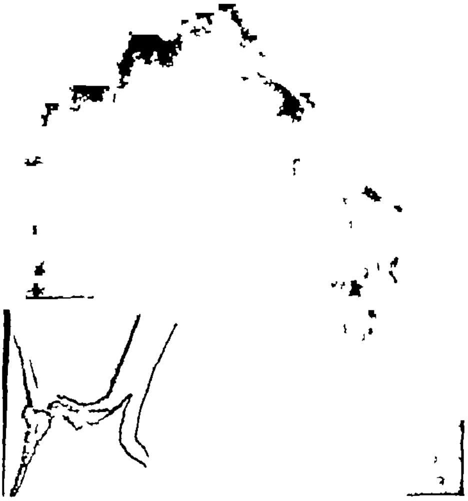

Fig 7 —*Case 11* Bronchography shows bronchial stump fistula persistence after treatment.

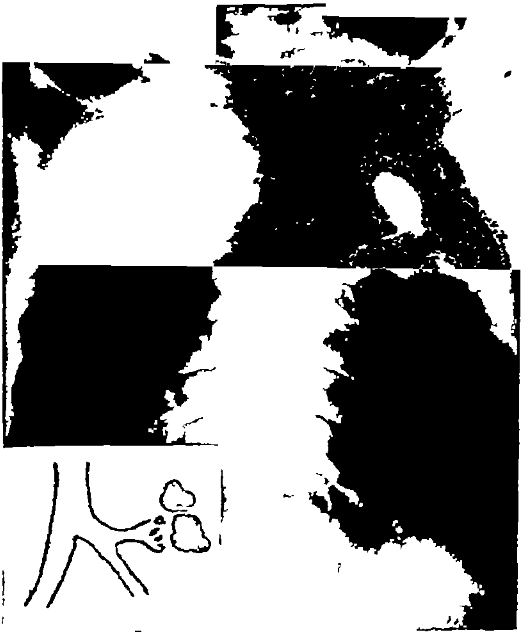

Fig 8 —*Case 12* Bronchography shows bronchial stump fistula persistence after treatment.

Case 10.—P. F. M., an 11-year-old white boy. A left pneumonectomy for tuberculosis was performed on May 2, 1950, and a bronchial stump fistula developed. Bronchoscopy on March 12, 1951, showed a 3 mm. opening of the suture. Bronchoscopy on April 14, April 24 and November 6, showed progressive reduction of the bronchial lumen. The fistula was not seen. Patient is in treatment for pocket and muscular layers and skin infection.

Case 11.—P. P., a 20-year-old white man. A right pneumonectomy for tuberculosis was performed on Feb. 26, 1948, and followed by corrective thoracoplasty on April 27. Underwater drainage was done on Nov. 25, 1949. Bronchoscopy on Jan. 23, 1951, showed a 5 mm. opening of the bronchial suture. Cauterization with 20 per cent sodium hydroxide was done with neutralization with acetic acid. Good evolution observed when bronchoscopy was again performed on February 10, March 12, and April 16. The fistula was considered to be completely closed. Bronchography on May 28, 1951, showed persistence of the fistula. Patient was discharged from the hospital and is now working under observation.

Case 12.—L. P. F., a 26-year-old woman. A right superior lobectomy for tuberculosis was performed on Aug. 21, 1953, as was a bronchoscopy on Oct. 27 when a 6 mm. opening of the bronchial suture was observed. Cauterization with 20 per cent sodium hydroxide was done with neutralization with acetic acid. Bronchoscopy on November 18 and December 1 showed great cicatricial reaction. The fistula was not seen on Dec. 1, 1953. Bronchography on Dec. 1, 1953, showed persistence of fistula. It was impossible to continue treatment due to the patient's bad condition. Patient is on bed rest, and her general condition is becoming worse.

Case 13.—B. B. J., a 32-year-old white man. A superior left thoracoplasty was performed for tuberculosis, the first stage on June 19, 1948, and the second on July 10. Residual cavity cavernostomy was done on May 3 with closure of the skin wound on Aug. 5, 1948. A left superior lobectomy was performed by residual cavity on March 22, 1950. Bronchoscopy on Feb. 1, 1951, showed a 2 mm. opening of the bronchial suture. Cauterization with sodium hydroxide was done with neutralization with acetic acid. Bronchoscopy and cauterization were done in the same way on March 8, March 24, and May 16, 1951, when gradual reduction of the bronchial lumen was observed. There were no clinical signs of fistula. The patient recovered and was discharged from this hospital on July 14, 1952.

Case 14.—S. F. S., a 34-year-old white man. A left superior lobectomy for residual cavity was performed on March 30, 1949, followed by superior left thoracoplasty, the first stage on Aug. 11, and the second on Aug. 29, 1949. Clinical signs of bronchial fistula appeared some days after operation. Bronchoscopy on Nov. 6, 1950, showed total opening of the bronchial suture. Silver nitrate cauterization of the bronchial stump was done November 6, November 21, and December 5 with no local changes. Bronchoscopy and 20 per cent sodium hydroxide cauterization and neutralization with acetic acid were performed on March 20, April 4, April 24, and May 7, 1951, with little local reaction. The fistula was always open. The patient was discharged from this hospital on request on Oct. 5, 1951.

DISCUSSION

We are not interested, in this paper, in the possible causes of postoperative fistula formation in patients submitted to excisional therapy for tuberculosis. Treating 14 such cases by sodium hydroxide cauterization we observed in all but two patients amelioration of the local conditions with fibrous tissue formation occluding the bronchial lumen. In two cases only did we observe the bronchial fistula closure at bronchoscopy. In all but two cases we observed improvement of the clinical signs of the bronchial fistula with total absence of it at the end of the treatment. We performed bronchography in 9 cases, which are considered bronchoscopically cured; five of these were definitely closed, four of them were not although they had no clinical signs of a fistula, and the fistula was not seen at bronchoscopy because the cicatricial tissue reduced the bronchial lumen by a longer and more irregular way These, probably, will be definitely closed in the future We have no bronchography of three cases, which were in good condition without clinical or bronchoscopic signs of fistula In two cases the fistula remained open and did not improve by the treatment We believe this fact had some relation to the poor general condition of these patients The endoscopic treatment of the bronchial fistula does not contraindicate any other means, such as thoracoplasty and drainage of the residual chest space, and these, too, have been performed The cauterization shortens the patient's treatment We definitely believe it is a good treatment for this postoperative complication, together with the other indicated means

SUMMARY

Fourteen cases of bronchial stump fistula after pulmonary resection for tuberculosis are presented Twelve cases were cured bronchoscopically, in which 9 bronchographies showed the fistula definitely closed in five cases, and not closed in the remaining four Three cases were not submitted to bronchography In only two cases was there clinical evidence of the fistula In two cases no benefits resulted from the treatment, because of the poor general conditions of the patients

AN ANALYSIS OF UNFAVORABLE RESULTS IN THE SURGICAL TREATMENT OF BRONCHIECTASIS

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THE clinical results in the surgical therapy of bronchiectasis are good.[1] A recent review of 221 cases of bronchiectasis revealed excellent results in 75 per cent. A fair result was obtained in an additional 16 per cent and a poor result in only 5 per cent of this series. It is the purpose of this communication to analyze certain factors possibly responsible for this group of unsatisfactory results.

METHODS

This study represents an evaluation of the unsatisfactory results in 46 cases (21 per cent) of 221 cases of bronchiectasis treated by surgical resection at the Mayo Clinic in a twelve-year period ending December, 1952. In all cases a thorough evaluation was made with special reference to the bronchoscopic, bronchographic, and pathologic findings.

Clinical results were determined by follow-up examination or direct questionnaire. This series includes 35 patients classified as having a fair result and 11 patients having a poor result. Our fair category consists of those who have some limitation of general activity but whose symptoms are not incapacitating. A poor result designates a patient who is little improved or is worse following operation (Table I).

TABLE I. CLINICAL RESULTS IN 221 PATIENTS UNDERGOING PULMONARY RESECTION FOR BRONCHIECTASIS

		GOOD		FAIR		POOR		DEAD	
	TOTAL	NO.	PER CENT	NO.	PER CENT	NO.	PER CENT	NO.	PER CENT
Unilateral resection	213	163	76	31	15	10	5	9	4
Bilateral resection	8	3	38	4	50	1	12	0	0
Total	221	166	75	35	16	11	5	9	4

ANALYSIS OF UNFAVORABLE RESULTS

In reviewing these cases certain factors were correlated with an unfavorable clinical result. An analysis of these various factors follows.

Age.—It was our feeling that children as a group did not obtain as gratifying a result from surgical therapy for bronchiectasis as did adults. This impression appears to be confirmed by the present study. There were 30 children in our original study. In 12 (40 per cent) of these the result was unfavorable. This figure is to be compared with an over-all unfavorable result of 21 per cent

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We had suspected, similarly, that our older age group might not fare well. We were pleased to note that of 24 patients aged 40 years or more, there were only 4 (17 per cent) unfavorable results. Age, within reason, therefore, is no contraindication to definitive surgical therapy.

Sex.—In our original series 132 patients were female and 89 male, a ratio of 3 to 2. Of the 46 patients obtaining an unfavorable result, 31 were female and 15 were male. This represents a ratio of 2 to 1. While this difference is not striking, it would indicate a less satisfactory response to surgical therapy in females than in males.

Hemoptysis.—A review of the duration of symptoms showed no correlation with the over-all result, either in the unfavorable group or in the series as a whole.

It was anticipated, however, that the symptom of hemoptysis might in some way be associated with an unfavorable result. This did not prove to be the case. In the original series, 57 per cent of patients had some degree of hemoptysis. Twenty-five (54 per cent) of our 46 patients with unfavorable results had hemoptysis. It seems evident that this symptom does not preclude a good result.

Residual Disease.—It was thought that residual disease might contribute to a less satisfactory result. This was not clearly the case. Analysis of data on the 46 patients obtaining unfavorable results revealed that 25 (54 per cent) had some residual bronchiectasis. This is to be compared with an incidence of 41 per cent in the over-all series.

In addition, of 85 patients in the original series who had residual disease, 65 (76 per cent) had a good result. It is apparent that residual disease is compatible with a good result.

Further analysis of this residual group revealed a definite difference in results between those patients having ipsilateral residual disease and those having contralateral residual disease. In patients with contralateral residual disease, 81 per cent obtained a good result, as contrasted with patients with ipsilateral residual disease of whom 68 per cent obtained a good result (Table II). Thus, it would appear that contralateral residual disease is better tolerated than ipsilateral disease, and every effort should be made initially to remove all disease present on the side on which operation is performed.

TABLE II. CLINICAL RESULTS IN PATIENTS WITH RESIDUAL DISEASE

	PATIENTS	GOOD RESULTS OBTAINED	
		NO.	PER CENT
Total with residual disease	85	65	76
Contralateral residual	57	46	81
Ipsilateral residual	28	19	68

Postoperative Complications.—Postoperative complications occurred nearly twice as frequently in this unfavorable group as in the series in general. The following postoperative complications were encountered: retention of secretions, empyema, empyema with bronchopleural fistula, hemorrhage, pulmonary edema, pleural effusion requiring thoracentesis, and pneumothorax. The incidence of these complications in the general series is given in Table III. A study of the incidence of postoperative complications in the 46 unfavorable results is given in Table IV. Reference to these tables suggests that the only postoperative complication influencing the clinical result is retention of secretions.

TABLE III. COMPLICATIONS OF PULMONARY RESECTION, 221 CASES OF BRONCHIECTASIS

COMPLICATION	CASES	PER CENT
Empyema	5	2.3
Empyema with bronchopleural fistula	8	3.6
Pleural effusion requiring thoracentesis	5	2.3
Pneumothorax	8	3.6
Hemorrhage	3	1.4
Pulmonary edema	1	0.5
Retained secretions requiring bronchoscopy	57	25.8

TABLE IV. COMPLICATIONS OF PULMONARY RESECTION, 46 CASES WITH AN UNFAVORABLE RESULT

COMPLICATION	CASES	PER CENT
Empyema	0	0
Empyema with bronchopleural fistula	3	6.5
Pleural effusion requiring thoracentesis	3	6.5
Pneumothorax	4	8.7
Hemorrhage	0	0
Pulmonary edema	0	0
Retention of secretions	21	45.7

Of the 46 patients manifesting an unfavorable clinical result, 21 (45.7 per cent) developed retention of secretions. This group is to be compared with the over all series of 221 patients undergoing resection in which only 57 (25.8 per cent) manifested retention of secretions. This is an impressive difference and it seems necessary to conclude that postoperative retention of secretions is of critical importance in determining prognosis (Table V).

TABLE V. INCIDENCE OF RETENTION OF SECRETIONS IN ENTIRE SERIES AND UNFAVORABLE RESULT GROUP

	CASES	RETAINED SECRETIONS	
		NO.	PER CENT
Entire series	221	57	25.8
Unfavorable result series	46	21	45.7

New Bronchiectasis.—Many authors[2,3] have expressed the opinion that bronchiectasis is not a progressive disease. Recent reports indicate that this is not entirely the case and our study would confirm the more recent observations.

Bronchographic evidence of new bronchiectasis was found in 24 patients. In 62.5 per cent of these a significant postoperative complication developed. This would suggest that postoperative complications play some part in the formation of new bronchiectasis. Furthermore 67 per cent of these 24 patients obtained an unfavorable result. New bronchiectasis is therefore a serious postoperative development and must be considered a frequent precursor of a poor result.

It is of further interest to note that there were 5 cases of documented progressive bronchiectasis in 3 of which the result was unsatisfactory.

These figures probably represent a minimum since only 51 postoperative bronchograms were obtained.

Sinusitis.—The relationship between bronchiectasis and sinusitis has been studied by a number of competent investigators, who reached divergent conclusions. Graham concluded that there is a definite causal relationship between the two[4] and suggested the possibility of sinusitis being related to unfavorable results in the surgical management of bronchiectasis.[5] Perry and King have noted a frequent occurrence of the two conditions, 66 per cent of their patients with bronchiectasis had sinusitis. These authors were not willing to conclude that a causal relationship existed. Riggins[6] encountered sinusitis in 30 per cent of his patients with bronchiectasis, but in two thirds of these, bronchiectasis preceded sinusitis.

In our study, an over-all incidence of sinusitis of 28.5 per cent was encountered, of the 46 patients with unfavorable results, sinusitis occurred in 41.3 per cent. Table VI compares the incidence of an unfavorable result in our cases with and without sinusitis. It is evident that a difference exists between the two groups, suggesting some real relationship between bronchiectasis and sinusitis which merits attention and treatment by the clinician.

TABLE VI. RESULT OF PULMONARY RESECTION FOR BRONCHIECTASIS ACCORDING TO OCCURRENCE OR ABSENCE OF SINUSITIS

	CASES	UNFAVORABLE RESULTS	
		NUMBER	PER CENT
Without sinusitis	158	27	17.1
With sinusitis	63	19	30.2
Total	221	46	20.8

Obviously, other conditions may well influence the results of the surgical treatment of bronchiectasis. The general allergic background of the patient may be a very important factor. Further study should be directed toward the role of this and other conditions in the prognosis of bronchiectasis after operation.

SUMMARY

A careful clinical appraisal and bronchographic review of 221 cases of surgically treated bronchiectasis were undertaken in an effort to determine the factors related to unfavorable results. Factors thought to be of major importance included postoperative complications and new bronchiectasis. Factors thought to be of less importance were residual disease, particularly ipsilateral residual disease, bronchiectasis in children, and sinusitis. A discussion of these factors is presented.

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TYPES AND INCIDENCE OF LUNG HERNIAS

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THIS report presents a case of spontaneous lung hernia brings up to date the incidence of this condition in the literature and classifies all cases of lung hernia published since 1925 Excellent and fairly comprehensive reviews of other aspects of the subject have already been presented by Montgomery and Lutz[41] Goodman,[23] Maurer and Blades[42]

In 1925 Montgomery and Lutz reviewed all the cases reported in the literature up to that time a total of 165 and classified as many as possible according to etiology and location In 1933, Goodman collected a total of 171 cases, and Maurer and Blades stated in 1946 that "less than 185 cases have been recorded in the medical literature " A number of individual case reports in the more recent medical literature quote one of these figures to indicate the rarity of lung hernias However, because no complete collection and classification of reported cases have been made since the review by Montgomery and Lutz in 1925 it seemed worth while to collect and classify all cases published since that time Sixty eight cases have been found in the literature between 1925 and June 1954 including some not mentioned by Goodman in 1933 and including the case presented herewith These 68 cases added to the 165 reported by Montgomery and Lutz bring the current total to 233 There are probably a few more because some articles on the subject were not available[1, 16, 17, 18, 27, 30, 40]

Of the 68 cases available for this study, 52 provided information on both etiology and location, 4 gave information only on etiology, 4 gave information only on location and 8 more had no information of value in classification As a result there are 56 cases available for classification in each category

A lung hernia may be defined as a protrusion of the lung beyond the normal confines of the thoracic cavity through an abnormal opening in the chest wall which is covered by a mesothelium lined sac and skin The term prolapse of the lung' has been used by some authors to describe a similar condition but one in which the pleura has been interrupted It is our opinion that there is no distinct difference between prolapse and hernia All such conditions should be classified as true hernias, since, by definition the lung has protruded abnormally through the confines of the thoracic cavity Mediastinal hernias are not related etiologically or pathologically to the hernias being considered here and are not included

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The basic classificatoin as suggested by Morel-Lavallée in 1849 is still accepted today and is as follows:[42]

ACCORDING TO LOCATION
- A. Cervical
- B. Thoracic
- C. Diaphragmatic

ACCORDING TO ETIOLOGY
- A. Congenital
- B. Acquired
  - (1) Traumatic
  - (2) Consecutive
  - (3) Spontaneous
  - (4) Pathologic

A consecutive hernia was defined as a hernia that had delayed onset after local trauma; now these are usually included with traumatic hernias. Likewise, today a diaphragmatic lung hernia is considered to be an impossibility because of the differential in pressures in the thoracic and abdominal cavities. In 1882, Beale[9] described 1 case of so-called *incarcerated hernia of the lung through the diaphragm into the abdominal cavity.* No similar cases have been reported since that time.

Table I gives the comparative figures for Montgomery and Lutz's series, the present series, and the combined data for all lung hernias when classified according to etiology. Table II gives comparative figures when they are classified according to location.

TABLE I. CLASSIFICATION ACCORDING TO ETIOLOGY

ETIOLOGY	MONTGOMERY AND LUTZ		HISCOE AND DIGMAN		COMBINED FIGURES	
	NO.	PER CENT	NO.	PER CENT	NO.	PER CENT
Congenital	29	17.6	11	19.6	40	18
Acquired						
1. Traumatic	83	50.3	32	57.1	115	52
2. Spontaneous	53	32.1	11	19.6	64	29
3. Pathologic	0	0	2	3.5	2	1
Total	165		56		221	

TABLE II. CLASSIFICATION ACCORDING TO LOCATION

LOCATION	MONTGOMERY AND LUTZ		HISCOE AND DIGMAN		COMBINED FIGURES	
	NO.	PER CENT	NO.	PER CENT	NO.	PER CENT
Cervical	16	20.5	17	30.4	33	24.6
Thoracic	62	79.5	39	69.6	101	75.4
Diaphragmatic	0	0	0	0	0	0
Total	78		56		134	

In the present series of 56 cases classified according to etiology (Table I) there were 11 congenital hernias. Five of these were cervical and 6 were intercostal, due primarily to costal malformations. The finding of 19.6 per cent congenital hernias is very close to the proportion reported by Montgomery and Lutz, 17.6 per cent. Acquired hernias made up 80.4 per cent of this series, and 71.1 per cent of these were traumatic in origin. In the group of 11 spontaneous cases, 8 were cervical and 3 thoracic, in contrast to Urbach's finding[62] of 7 supraclavicular, and 18 thoracic. The 2 pathologic cases were due to severe infections of the lung and thoracic wall in children.[27, 59]

Of the 36 cases here classified according to location 17 were cervical. Although it has been stated that cervical hernias are most commonly congenital,[42] in the present study there were more cervical hernias with a spontaneous onset during or after late childhood than there were congenital cervical hernias. It is true that those cervical hernias with late onset could have been attributed to congenital weakness of Sibson's fascia but these have been considered here to be of spontaneous origin. It is of interest that 3 cases of bilateral cervical hernias have been reported, 2 congenital in infants[13, 49] and 1 spontaneous in an adult.[63] Each case of bilateral hernia was counted as 1 case only in the Tables. Suffice it to say that most thoracic hernias follow trauma of various degrees ranging from simple rib fractures to extensive operations.

On physical examination of a patient with lung hernia one notices a bulge on the chest wall only when the intrathoracic pressure is increased. This is usually associated with chronic cough, pain, and a palpable defect in the chest wall. The cervical hernias bulge between the scalenus anticus muscle and the sternocleidomastoid muscle. Thoracic hernias are most commonly found first, at the sites of previous trauma or injury; second, anteriorly in the interspace near the costochondral junction; and third, in the interspaces posteriorly near the vertebral bodies. The latter two are sites of spontaneous herniations and are explained by the deficiency of the external intercostal muscles anteriorly and the internal intercostal muscles posteriorly. The lower incidence of hernias posteriorly may be due to the support rendered by the latissimus dorsi, trapezius and rhomboid muscles.

X-rays usually confirm the physical findings, and in special projections the air bearing tissues of the lung can be seen to project outside the thoracic wall.

CASE REPORT

F. F., a 67 year old white man, was admitted to the Albany Veterans Administration Hospital for the second time on Jan. 19, 1954, with the chief complaint of pain in the abdomen of three to four days duration.

For several days prior to admission the patient had an upper respiratory infection with cough, hoarseness and dyspnea. While coughing about three days prior to admission, the patient felt a sudden mid abdominal pain that felt "as if something were ripping apart." The pain remained constant, prevented sleep, was worse when the patient reclined and was aggravated by coughing. The patient had had some dyspnea with wheezing, especially on exertion, for the previous eight years but he had never been told that he had heart trouble or high blood pressure.

Past history revealed that he had been a beer truck driver for twenty years. He had had a cholecystectomy in 1940 and repair of a ventral hernia two months later. A well healed right rectus scar and absence of abdominal hernias were noted on the first Albany V. A. H. admission in November 1952.

Review of system showed that the patient's general health had been good and he denied excessive coughing, chest pain and hemoptysis.

Physical Examination.—The temperature was 100.4° F., pulse 128, blood pressure 1[illegible]80 and weight 268 pounds. The patient was a well developed, very obese, elderly white man who was in moderate respiratory distress and wheezing but appeared to have good color. The chest showed increased anteroposterior diameter and a few coarse rales throughout. The heart was negative except for sinus tachycardia. The abdomen showed an eight inch right paramedian scar. There was a large ecchymotic area with slight tenderness in the right upper quadrant and to the right of the umbilicus (Fig 1) There were no hernias noted Two plus edema of the feet and ankles was noted. The physical examination was otherwise noncontributory

Laboratory and X ray Data The white blood count was 9,000, with a normal differential, hemoglobin 13 Gm , and hematocrit 43 Urinalysis showed a high specific gravity of 1 013 after a Mosenthal concentration test Urine cultures repeatedly showed *Staphylococcus aureus*, coagulase positive The nonprotein nitrogen was 40, Folin blood sugar 126 Total serum protein was 7 9 per cent with an albumin of 4 2 The serologic test was negative The platelet count was 304,000, with normal bleeding and coagulation time Liver chemistries and electrolytes were normal

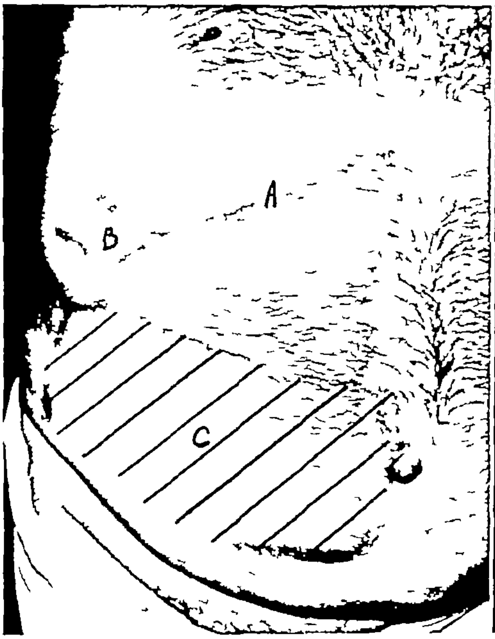

Fig 1

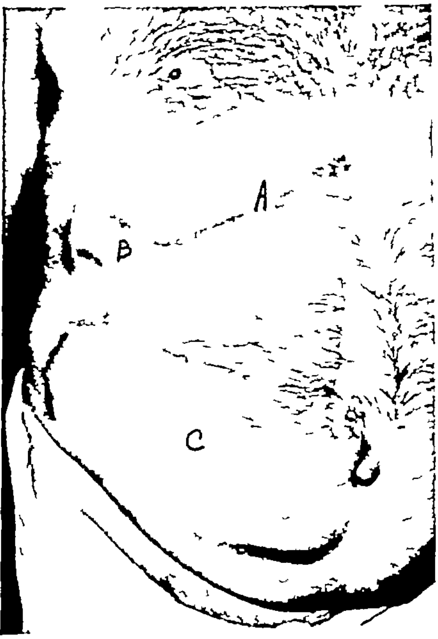

Fig 2

Fig 1 —Patient in standing position *A* Costal margin *B* Seventh interspace *C*, Area of ecchymosis

Fig 2 —Same position Hernia appears at *B* with Valsalva maneuver

Course in Hospital X ray of the chest on admission showed a pneumonitis and some atelectasis in the right lower lobe The patient was treated with penicillin, bed rest, Isuprel, saturated solution of potassium iodide, and an 800 calorie low salt diet Further medical work up revealed that the patient's dyspnea was on the basis of chronic pulmonary disease and not cardiac failure The patient's general condition and dyspnea improved moderately on the treatment just described

At the time of admission it was noted that he had an area of ecchymosis in the right upper quadrant and to the right of the umbilicus For a few days this ecchymotic area gradually enlarged, it then began to subside and had almost completely disappeared by the tenth hospital day This region and the right upper quadrant were tender throughout this time The ecchymosis was thought at this time to be due to rupture of the superior epigastric artery precipitated by coughing

On Feb 23, 1954, an intravenous pyelogram revealed bilateral hydronephrosis and hydro ureter A severe ulcerating chronic cystitis was found which was treated with prolonged drainage and antibiotics until April 15, 1954

Throughout this period the patient continued intermittently to complain of pain which was especially aggravated by coughing, in the right upper quadrant and in the vicinity of the right costal margin About two months after the ecchymosis on the abdominal wall had disappeared, the patient noted that a lump protruded in the right upper quadrant when intra abdominal pressure was increased or when he coughed A routine chest x ray showed clearing of the pneumonitis but there was still a very slight amount of atelectasis at the right base No hernia was noted. Physical examination at the time revealed that upon straining, a bulge about 5 inches in diameter appeared in the region of the right costal margin (Fig 2) This bulge subsided spontaneously within 15 seconds after the patient stopped straining The skin was loose and thick and no crepitus was present When the protrusion was palpated as it reduced, a defect could be felt in the cartilage of the costal margin, between the seventh and eighth ribs This palpable defect extended for about 2 inches above and below on either side of the costal margin

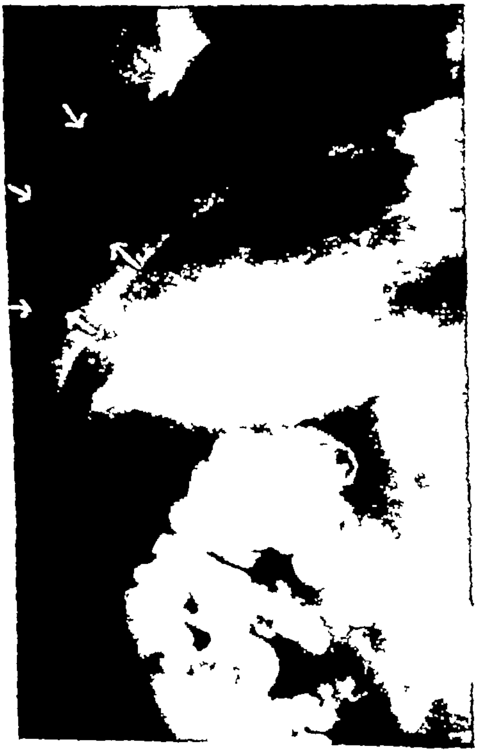

Fig 2—Valsalva maneuver with barium in hepatic flexure

Both a barium enema and a small bowel series failed to reveal any bowel entering the hernia The patient was fluoroscoped and probable lung tissue could be seen passing into the hernia and it was noted that the seventh and eighth ribs spread as the patient strained X rays taken at this time revealed a definite bulge of a relatively radiolucent area that could be seen protruding into the hernia (Fig 3) This was thought to be lung and was noted on the films only when the patient was straining A bronchogram was performed on May [illegible] 1954 and revealed the terminal bronchi of the lateral segment of the right lower lobe extending to the herniated portion of the lung as well as some of the terminal radicals of the right middle lobe (Fig 4) The minor fissure was low in position and showed thickening at its lateral end There was also thickening of the pleura along the chest wall

Throughout his period of hospitalization the patient was maintained on a low calorie diet, 800 calories per day, but in spite of this his weight never went below 240 lbs. He surreptitiously obtained food and did not cooperate. The patient was considered unfit for surgical intervention because of extreme pulmonary emphysema, obesity, and poor renal function. He was fitted with a special abdominal binder which gave prompt relief from symptoms. Accordingly he was discharged on a program of weight reduction diet and close supervision in the follow up clinic.

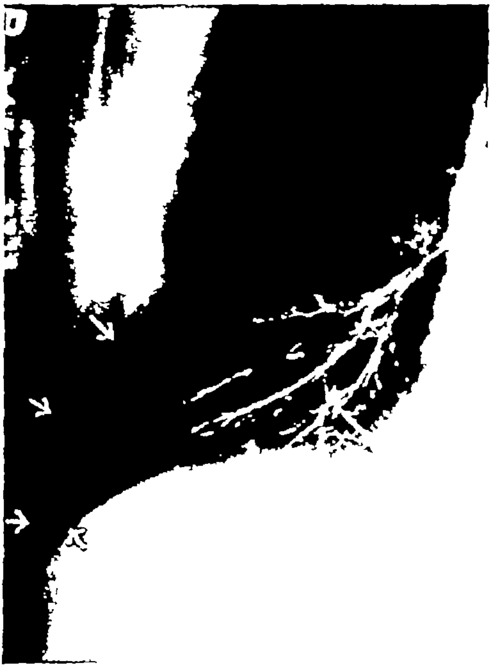

Fig. 4.—Bronchogram. Further illustrates extrusion of lung tissue on Valsalva maneuver.

Comment.—This case is of interest in that it presents a complete picture of the development of a spontaneous thoracic lung hernia. The onset of ecchymosis and pain dates the rent in the thoracic wall. The bulge, however, was not noted for about two months. This was probably due to muscular spasm at first and then the slow enlargement of the bulge to a noticeable size. Second, this is unusual in that the defect goes through the costal margin between the seventh and eighth ribs, thus making it imperative to determine whether this is a hernia of the lung or the peritoneal contents.

SUMMARY

1. A case of spontaneous thoracic lung hernia is presented.
2. There are at least 233 cases of lung hernia reported in the literature.
3. Sixty previously unclassified cases have been classified according to etiology and location. These have been compared to and combined with the only other similar series done in 1925.

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A TECHNIQUE OF SEGMENTAL RESECTION OF THE LUNG*

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INTRODUCTION

During the past several years an increasing number of segmental resections has been performed for the removal of pulmonary disease. This has been particularly true in tuberculosis, but the procedure is suitable for other localized disease.

Techniques of segmental resection vary throughout the country, but most surgeons follow the method of starting from the stem bronchus and dissecting the pulmonary parenchyma along the major bronchus until a segmental branch is reached. Decision is made on the basis of anatomical relationships as to whether this is the bronchus leading to the segment to be removed. Confirmation is frequently made by occluding the bronchus while the anesthetist inflates the lung. This method has a few disadvantages. Frequently it is time consuming, particularly when the hilus of the lung is scarred and fibrotic. Anatomical relationships, also, may be difficult to assess, either because of anatomical variations or because of distortions due to disease.

During the course of development of our technique for segmental lung resections, a method of identification of any segmental bronchus has been found which has made for easy isolation of the proper bronchus. This technique depends upon the fact that the bronchus is the least elastic structure within the hilus of the lung. Therefore, traction exerted on the periphery of the lung causes the bronchus leading to that area to stand out as a tight cord discrete from all other structures. This tight cord can be identified readily where it leaves the main bronchus by palpation between the thumb and index finger.

To date approximately 75 segmental resections have been done using this method of bronchial identification and there have been no operative mishaps due to anomalous anatomy or faulty anatomical identifications. Because of the simplicity this method gives to bronchial identification and the ease with which surgical residents have grasped the principles, the method was thought to warrant this report.

PROCEDURE

Resection of the apical segment of the right upper lobe will be chosen as a descriptive example (Fig. 1). The visceral pleura is grasped with a lung forceps immediately adjacent or distal to the lesion to be resected and traction

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*From the Veterans Administration Hospital, Albuquerque, N. Mex.

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RESECTION APICAL SEGMENT RIGHT UPPER LOBE

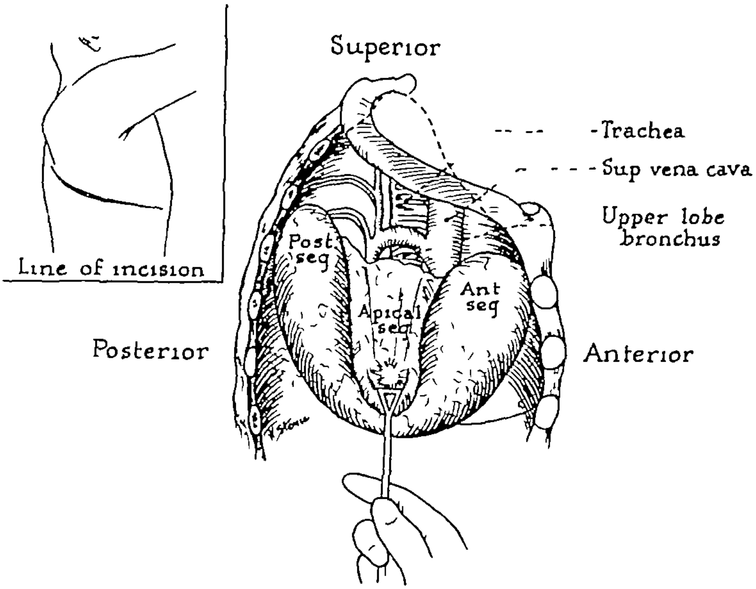

Fig 1

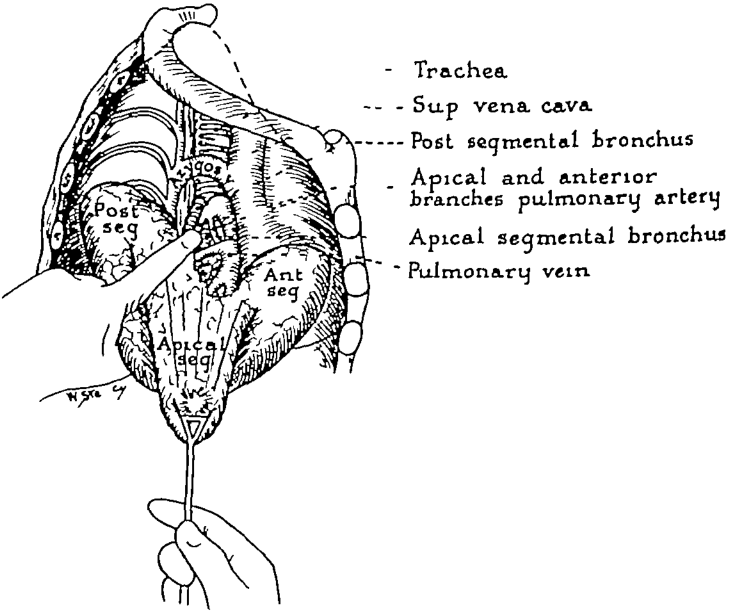

Fig 2.—Note Palpation in this illustration is being done with the tip of the index finger palpating against the tip of the thumb

is applied to the lung Care is taken that the clamp be placed within the confines of the involved segment After incision the pleura is then dissected from the superior portion of the hilus with a blunt dissector

The superior portion of the hilus is then palpated with the index finger and thumb of one hand while traction is exerted on the distal lung parenchyma with the lung clamp as illustrated in Fig 2 Palpation at the hilus will ordinarily identify the major bronchus with ease, and a series of small hard lumps will be felt where the segmental bronchi bifurcate from the major bronchus It is in this area that the palpatory identification of the segmental bronchus will be made as it leaves the *principal bronchus* Ordinarily the whole length of the bronchus leading to the segment containing the lesion will be palpable as a tight cord easily distinguished from other bronchi and vessels If a great deal of fibrosis of the lung is present it may be necessary to give several sharp tugs in order to make positive identification of the bronchus at the *hilus* This identification is made with the segmental bronchus grasped between thumb and index finger and the bronchus thus identified is *kept in the grasp of these fingers* With the bronchus located it is a relatively simple procedure to push back the pulmonary parenchyma at the place where the bronchus is nearest the hilar surface and isolate it from the surrounding structures (Fig 3) Usually arteries and veins may be pushed aside without ligation until the bronchus is isolated although the segments of the left upper *lobe* for example are usually most easily resected after preliminary ligation of the segmental arteries A

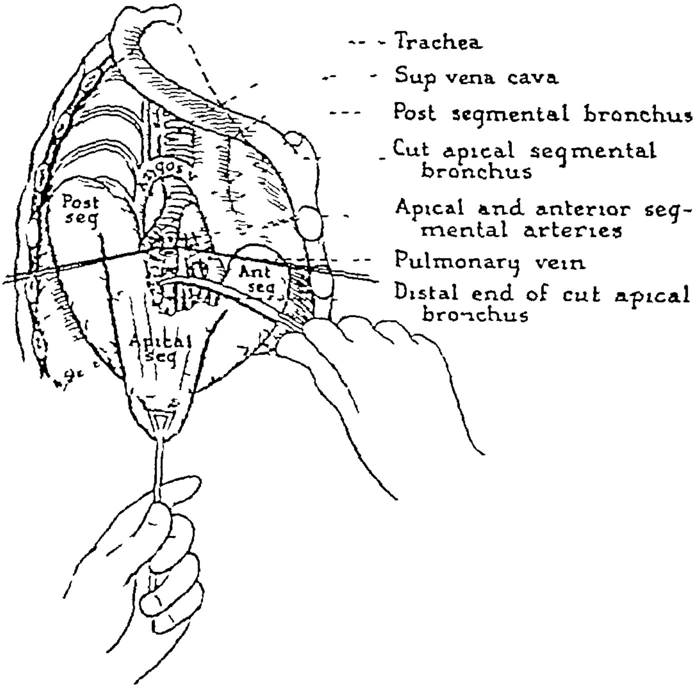
Trachea
Sup vena cava
Post segmental bronchus
Cut apical segmental bronchus
Apical and anterior segmental arteries
Pulmonary vein
Distal end of cut apical bronchus
Azgos v
Post seg
Ant seg
Apical seg

Fig 3

curved clamp is then passed under the bronchus to retain its identification Preliminary stay sutures are then placed proximally in the bronchus (Fig 3) a clamp is placed distally, and the bronchus is cut and closed

Traction is then applied to the clamped distal bronchus and the hilar vessels further exposed by blunt dissection (Fig 3) Vessels entering the involved segment will in this manner be readily identifiable as tight cords coursing into the parenchyma adjacent to the bronchus

Following ligation of the segmental pulmonary artery, traction away from the hilus is applied to the distal cut bronchus, while simultaneously the parietal pleura, in the region of the intersegmental plane, is pushed toward the hilus with the other hand (Fig 4) In this manner the segment is stripped along the intersegmental veins from the adjacent segments Bleeding is then controlled in the intersegmental planes and the bronchial stump is checked for air leaks

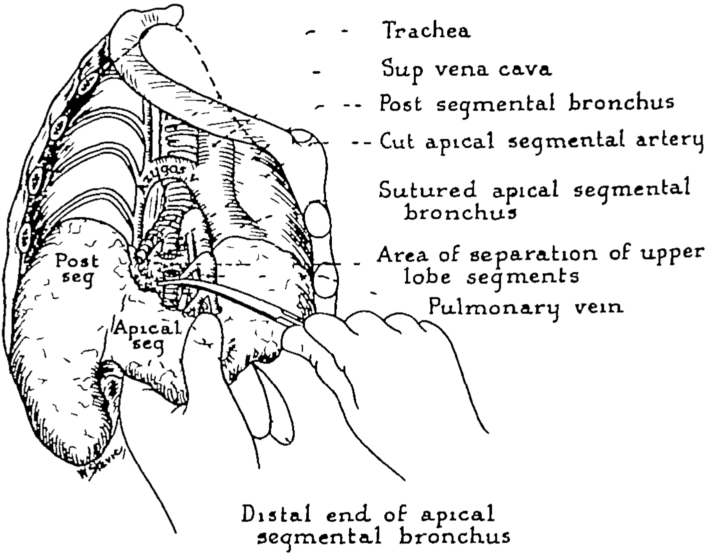
Trachea
Sup vena cava
Post segmental bronchus
Cut apical segmental artery
Sutured apical segmental bronchus
Area of separation of upper lobe segments
Pulmonary vein
Azygos
Post seg
Apical seg
Distal end of apical segmental bronchus

Fig 4

DISCUSSION

Advantages of this method have been as follows

1 The amount of dissection necessary to identify positively the involved bronchus has been greatly reduced

2 Anomalous arteries are no longer a hindrance or hazard since, by securing the bronchus first, arteries entering the segment are easily identified and the dangers of interfering with arterial supply to adjacent segments are greatly reduced

3 When two segments are involved in the disease process, such as apical and posterior segments on the right side, traction on the lung peripherally, on either segment, will cause both segmental bronchi to tighten, informing the operator early that both segments will have to be removed

4. Segmental bronchi may be approached from any side of the hilus, depending on the pathology present

5 A greater portion of the segmental artery is exposed allowing better control of the ligating process It is not unusual to have 2 to 3 cm. of free artery available for ligation

6 Subsegmental resections are rendered extremely easy, since the entire bronchial tree on the involved side does not have to be dissected and only the involved bronchus need be exposed

7 Normal segments which one wishes to preserve, such as the superior segment of the lower lobe in patients with bronchiectasis, can be identified readily by the technique Resection can be done on the main bronchus distal to the identified segmental bronchus

CONCLUSION

A method of segmental resection of the lung depending upon bronchial identification by palpation is offered which has greatly facilitated the performance of this type of operation in our hands

PUNCTURE OF THE CERVICAL ESOPHAGUS IN THE PALLIATIVE TREATMENT OF CARCINOMA OF THE ESOPHAGUS

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OWING to the nature and site of the lesion, there remains a large place for the palliative treatment of carcinoma of the middle third of the esophagus

Many types of tube have been used for insertion through the stricture That described by Souttar[1] in 1924 is of ingenious design and has proved its worth A disadvantage common to such tubes is their tendency to pass on along the bowel shortly after their insertion The rather frequent premature passage of the Souttar tube caused us to try the method of passing a slender polythene tube through the stricture, the tube being brought out through the nose or mouth In Souttar's original article he describes the use of Hill's probe, a silver wire covered by a fine rubber tube brought out through the mouth and "acting as a permanent dilator alongside which food can pass through the stricture " The method of use of a narrow-bore plastic tube employs the same principle with the added advantage that the tube may be used for feeding the patient In our experience, this method provided for satisfactory feeding through the tube, but in some cases did not maintain an adequate passage for mucus and saliva The presence of the tube in the nose or mouth causes discomfort In an attempt to overcome this latter disadvantage, it was decided to bring the tube out in the neck A small trocar and cannula were introduced into the cervical esophagus by the method described hereafter, and the polythene tube was brought out through the cannula

This procedure overcame the problem of the discomfort of an oral or nasal tube and provided a means of feeding the patient As already stated, the swallowing of food and saliva was not adequately assisted

It was then decided to revert to the use of the Souttar tube and to employ the method of cervical esophageal puncture as a means of anchoring the tube by a thread brought out in the neck and tied over a button lying on the skin By this method the tube can be kept in position for long periods of time even when it is no longer firmly gripped in the malignant stricture Souttar in describing his tube of spiral wire, mentions the use of Symond's gum-elastic tube which was kept in position by means of a thread brought out through the mouth and fastened round the ear

The Introduction of a Trocar and Cannula Into the Cervical Esophagus — In spite of its deep situation, its proximity to important and vulnerable struc

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tures, and the apparent danger of infection of the tissue planes, it is possible to puncture the cervical esophagus safely with a trocar and cannula in the following manner

The patient is given penicillin by injection to cover the operation and the first postoperative week The procedure is carried out under general anesthesia with endotracheal intubation The esophagoscope (Negus pattern) is passed through the cricopharyngeal sphincter to the level of the sternal notch The esophagoscope is rotated in its long axis so that its oblique lower orifice points forward and to the left toward the anterior border of the left sternomastoid muscle The upper end of the esophagoscope, manipulated by the assistant, is gently depressed and moved slightly to the right This maneuver brings its lower end forward and to the left It is then withdrawn until the operator can feel its lower orifice through the tissues of the neck at the anterior border of the sternomastoid just above the left clavicle Alterations in the position of the esophagoscope should be made only when the instrument is being withdrawn

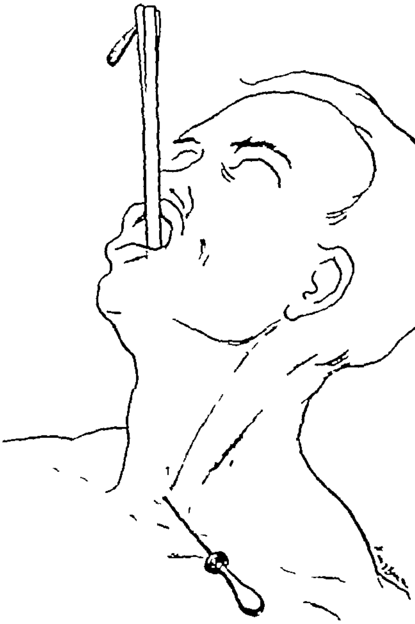

Fig 1 —Drawing to show the method of puncture of the cervical esophagus The esophagoscope is in the correct position to receive the trocar and cannula

The head should not be extended as this renders the tissues on the anterior aspect of the neck taut and the esophagus is less accessible In a thin person it is easy to feel the open lower end of the esophagoscope Even in fatter, short-necked individuals it is not difficult It is our custom to introduce a narrow gauge needle first of all The needle is inserted through the skin at the anterior border of the left sternomastoid just above the clavicle, and is pushed on into the esophagoscope The needle passes slightly upward and medially, but there is no difficulty in determining its direction as it is merely passed straight into the lower orifice of the esophagoscope which can be readily felt The only other anatomical structure to which attention should be paid is the trachea The needle is kept close to the left side of the trachea As the esophagoscope has been rotated, its long beak lies on the side opposite to the point of entry of the needle, which is thus prevented from passing across the orifice of the esophagoscope When the assistant has confirmed that the needle has entered the esophagoscope, the needle is withdrawn and a trocar and cannula inserted in the same manner We have used a trocar and cannula 10 cm long and 3 mm in diameter (Fig 1)

A trocar and cannula have been introduced into the cervical esophagus by this method on nine occasions without immediate or late complications

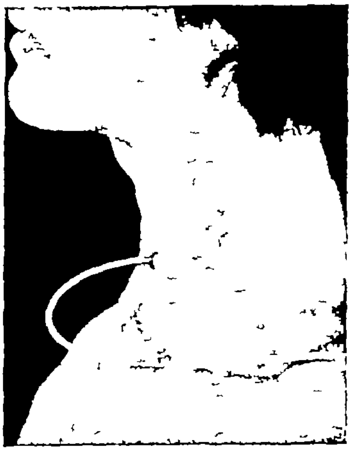

Fig 2 —A patient suffering from carcinoma of the middle third of the esophagus with a polythene tube passed through the stricture and brought out in the neck.

Dissections of the neck have been carried out in the cadaver with the trocar and cannula in position The instrument passes medial to the sternomastoid, through the sternohyoid and sternothyroid muscles, and then between the trachea and the left lobe of the thyroid gland just below the thyroid isthmus The esophagoscope, when correctly placed, causes the trachea to move slightly forward and to the right, and causes a local bulging of the esophagus to the left The recurrent laryngeal nerve remains in the groove between the trachea and the esophagus, and the trocar and cannula enter the esophagus to the left of the nerve with the esophagus in its displaced position The carotid artery is at a safe distance to the left if the trocar and cannula are kept close to the trachea

This procedure may be used in the following ways 1, the introduction of a polythene tube into the esophagus, and 2, the passage of a thread into the esophagus in order to anchor an esophageal tube

1 The esophagoscope is passed down to the growth A polythene tube (size 3) is threaded through the stricture using Jackson side-grasping esophagoscopy forceps The esophagoscope is withdrawn into the neck and rotated The trocar and cannula are inserted as already described The

polythene tube must be long enough to project from the upper end of the esophagoscope even when the instrument has been withdrawn into the neck The stem of a Jackson esophageal dilator is then passed through the cannula and up the esophagoscope The upper end of the polythene tube is attached to this stem which is then withdrawn through the cannula bringing the polythene tube after it There may be some difficulty in getting the polythene tube to enter the cannula because of the obliquity of the latter It is best as soon as the tube comes up against the cannula to withdraw the cannula with the polythene tube following it Attempts to force the polythene tube through the cannula may detach it from the stem or may result in its being cut across by the end of the cannula The polythene tube is gently pulled out until as seen through the esophagoscope it is not looped in the cervical esophagus (Figs 2 and 3)

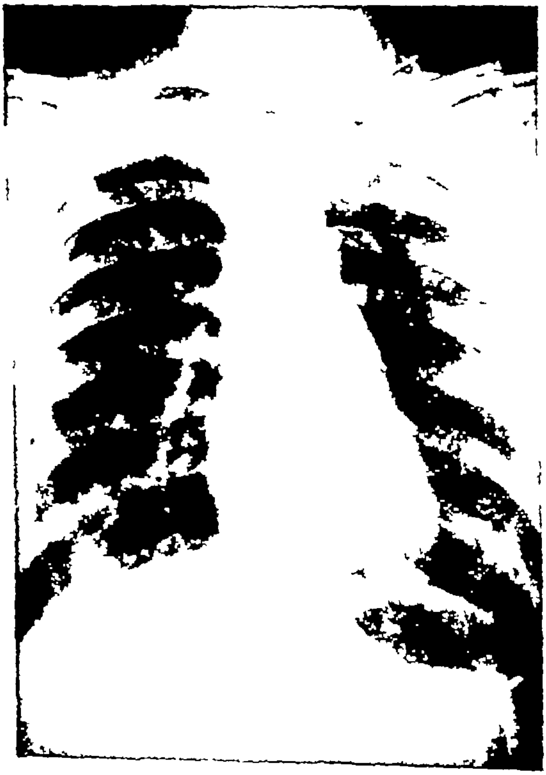

Fig 2 —X ray of a case of malignant obstruction at the cardia showing a polythene tube filled with Lipiodol passed into the stomach and brought out in the neck

2 A double thread (Mersilene size 0 or 1 noncapillary serum proof braided surgical silk) is attached to the upper end of a Souttar tube The esophagoscope is passed down to the growth and the tube inserted The procedure for bringing the thread out in the neck is the same as has been described for the polythene tube except that there is no difficulty in withdrawing the thread through the cannula The thread is pulled out gently until as seen

through the esophagoscope, there is no slack thread in the esophagus The thread is tied over a stainless steel button which has two holes in it A small dressing is applied over the button (Figs 4 and 5)

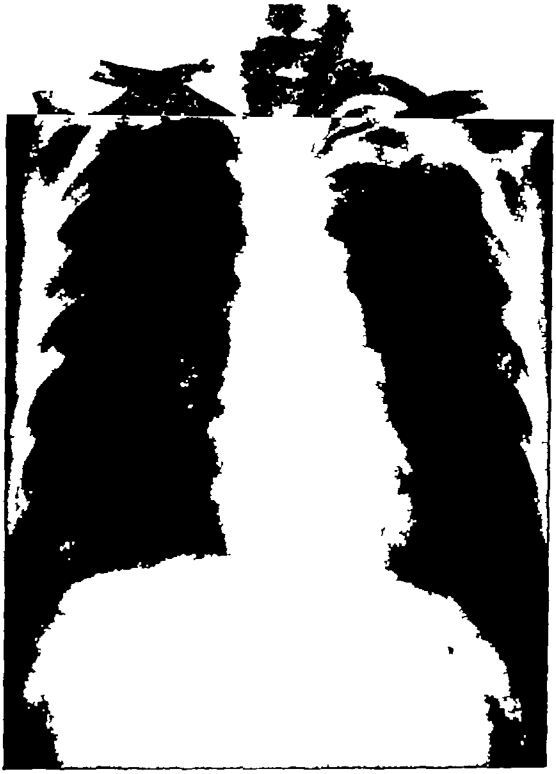

Fig 4 —X-ray of a patient with a Souttar tube through a malignant stricture of the middle third of the esophagus The tube is anchored by means of a thread to a button which is lying on the skin of the neck.

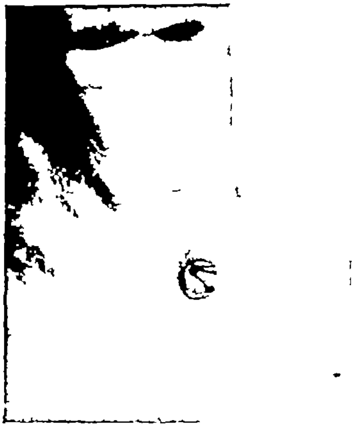

Fig 5 —Photograph showing the position of the button to which the Souttar tube is anchored This photograph was taken after the button had been in position for ten weeks

Postoperative Course.—During the first forty-eight hours, the patient will complain of sore throat, and sometimes there is regurgitation of mucus and saliva. For about three days he may have pain radiating to the left ear. A small amount of granulation tissue tends to form at the site of skin puncture. There is slight but persistent discharge of pus from the puncture hole. The skin under the button is cleaned and a fresh dressing applied daily. On no occasion has there been spreading infection and there has been no discharge of food or saliva.

At a second esophagoscopy performed on one patient after the thread had been in position for two months, the point of entry of the thread into the esophagus was clean. There was no narrowing of the esophagus at this level.

CASE REPORTS

CASE 1.—M. S., a 37-year-old woman, was admitted to the hospital on May 18, 1954, because of dysphagia of three months' duration. She was able to swallow fluids only. She suffered from thirst and regurgitation of slime. The esophagus was narrowed in its middle third by a neoplasm, a biopsy of which showed squamous-cell carcinoma. On bronchoscopy, the lower part of the left main bronchus was seen to be narrowed by a prominence of the posterior wall.

After dilatation of the stricture a slender polythene tube was passed through it and brought out through the nose. The patient was able to swallow saliva, liquids, and a little semisolid food for two weeks when the tube was accidentally pulled out during sleep.

The polythene tube was again passed through the growth and on this occasion brought out in the neck. It remained in position for twenty-six days and then came out during a bout of retching.

After the cervical introduction of the tube the patient complained of pain radiating up to the left ear. This symptom passed off after three days. During the first twenty-four hours she regurgitated some mucus and saliva. Thereafter she was comfortable. She was, to begin with, vaguely conscious of the foreign body in the esophagus. This feeling disappeared after four days. Some granulation tissue formed at the point of entry of the tube through the skin. There was slight discharge of pus but no leakage of food or saliva. The patient was able to swallow fluids and occasionally some semisolids but with considerable difficulty. She frequently regurgitated mucus and saliva. Food was given through the tube and satisfactory hydration and nutrition maintained.

On Aug. 2[illegible], 1954, a Souttar tube was inserted through the growth and anchored to a button in the neck. The tube remained in position for three months until she died. During this time the patient was able to swallow liquids, semisolids and well masticated solid food without difficulty. There was no further regurgitation. She died suddenly at home following hematemesis.

Comment.—In this case puncture of the cervical esophagus was performed on two occasions without difficulty. Only when an anchored Souttar tube was used was satisfactory palliation achieved.

CASE 2.—G. K., a [illegible]-year-old man had had dysphagia for three months. He could swallow liquids only. He was wasted and dehydrated. A squamous-cell carcinoma was found in the middle third of the esophagus. At bronchoscopy there was seen to be bulging of the [illegible] wall of the lower part of the trachea and of the upper end of the left main bronchus. The carina between the main bronchi was broadened and shortened anteroposteriorly.

On Nov. [illegible], 1954, a Souttar tube was introduced through the stricture and anchored by means of a Mersilk [illegible] silk thread to a button in the neck. Some venous bleeding occurred from the posterior [illegible] the pharynx but was readily controlled by finger pressure and [illegible] of the [illegible] wall. The patient had very little postoperative discomfort and swallowed soft foods without difficulty Six weeks after insertion of the tube, he had gained 8 pounds There was persistent slight discharge of pus from the puncture hole but no leakage of food or saliva

Two months after insertion of the tube, the patient was readmitted with dysphagia X ray showed the tube still in position. At esophagoscopy, the thread was seen lying on the left side of the esophagus and, lower down, it lay against the anterior wall The point of entry of the thread was clean There was no evidence of ulceration or stricture formation at the level of puncture The Souttar tube was found to be blocked by impacted food A bougie was passed into the tube On withdrawal of the bougie, the tube tended to move upward with it The tube was apparently lying quite loosely at the site of the growth. The tube was gripped with forceps and cleaned with a brush without extracting it from the esophagus. After withdrawal of the esophagoscope, the button was seen to be hanging loosely, about half an inch of thread having emerged from the cervical tract When the patient swallowed some food the thread retracted and the button again lay flush with the skin After the cleaning of the tube, swallowing was again easy, the patient's condition rapidly improved, and he remains free from dysphagia

DISCUSSION

Palliation in cases of malignant esophageal obstruction is difficult The great variety of methods described is evidence of their limited success This is due not only to defects in the methods, but to the fact that distressing symptoms may arise from bronchial involvement and pulmonary infection while the palliative measures are directed mainly toward relief of dysphagia

Though intubation methods through the esophagoscope are useful, it is, of course, imperative that thoracotomy be performed if there is any prospect of excision of the carcinoma In certain cases, it is obvious without exploration that the lesion is irremovable, and one may proceed at once to intubation. In other cases, the lesion is found at thoracotomy to be inoperable In such circumstances, we have preferred to intubate through the esophagoscope rather than to insert a tube after incising the esophagus as described by Mackler and Mayer[2] No attempt can here be made to assess the relative value of simple intubation and the procedure of esophago-jejunostomy as described by Allison,[3] or that of replacement of the resected carcinomatous segment by a plastic tube as described by Berman[4] To some extent, the nature of the case will dictate the method which is most suitable

An intubation method should be effective over an adequate period of time, it should allow for the passage of food and saliva, and it should not be associated with physical or mental suffering In dealing with carcinoma of the esophagus it is important to be sure that procedures described as palliative do in fact, bring comfort to the patient Gastrostomy and jejunostomy though providing for feeding, are widely condemned because of the mental and physical suffering they cause

A palliative measure may fail if it has to be repeated too often This objection applies in many cases to repeated bouginage It also applies to intubation methods in which the tube tends to pass through the stricture soon after its insertion It is hoped that the method of anchoring the tube which is described may remove the necessity for repeated insertion of the tube and so en hance the palliative value of intubation The thread prevents the downward passage of the tube It does not prevent its movement upward Fortunately the upward displacement of a tube of the Souttar pattern is rare

The great advantage of the use of the Souttar tube alone is that the patient is unaware of its presence The method described here has the disadvantage that a button is present on the skin of the neck Though not causing pain, its long continued presence may make the patient who is unaware of the nature of his illness suspect that he is suffering from an incurable condition This is a defect in the method but it may be outweighed by the advantage of having a point of fixation for the tube

The fact that spreading infection in the tissue planes of the neck has not occurred may be due partly to the action of the antibiotic, and partly to the fact that drainage can occur along the thread both into the esophagus and through the skin

Attempts at palliation using a slender polythene tube may fail if the patient is left with a tube emerging from the nose or mouth After an initial day or two of discomfort the patient is much more comfortable if the tube enters the cervical esophagus below the cricopharyngeal sphincter

In our experience the use of the anchored Souttar tube is more successful than methods employing a long slender plastic tube

SUMMARY

A method is described of puncture of the cervical esophagus with a trocar and cannula The cannula is used for the introduction of a thread in order to anchor a tube passed through a malignant stricture of the middle third of the esophagus The cannula may also be used as a means of introducing a slender polythene tube into the esophagus

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THE TREATMENT OF VENTILATORY INSUFFICIENCY AFTER PULMONARY RESECTION WITH TRACHEOSTOMY AND PROLONGED ARTIFICIAL VENTILATION

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IN THE treatment of pulmonary tuberculosis it has been found possible to carry out major surgery on patients with ventilatory insufficiency (maximal breathing capacity as low as 18 L per minute) Most of these patients will have as pronounced ventilatory insufficiency after the operation as before Their sputum, however, may became negative to guinea pig tests, and they may leave the hospital and take up their former work As the operative mortality in this group is comparatively low, more such cases are accepted for surgery The immediate postoperative management is most important in these cases It may be necessary to connect the patient with a machine for artificial ventilation This may be done intermittently for short periods during the first days after operation in order to wash out the carbon dioxide, until the patient gets strength enough to keep the carbon dioxide content down by his own respiration

On the other hand, it may be necessary to use artificial ventilation continuously for more than a week in a severe case with, for instance, a pneumonia in the only functioning lung, until this pneumonia has been resolved and the patient can take over the ventilation himself

PRINCIPLES FOR POSTOPERATIVE TREATMENT

1 *Intratracheal aspiration* with a rubber catheter introduced through the nose is used intermittently in cases with a low maximal breathing capacity, i e , 20 to 35 L per minute These patients are often not able to cough up the accumulated secretion The small volume of expired air will only carry the secretion from the bronchi up into the trachea The patient is too weak to continue coughing until the accumulated secretion is expectorated

2 *Tracheostomy* is the next step to be taken if the patient does not improve and in spite of frequent aspirations develops a carbon dioxide retention The tracheostomy will diminish the dead space by approximately 100 ml , thereby improving alveolar ventilation If the arterial carbon dioxide tension is above 70 mm Hg, we consider it advisable to perform a tracheostomy

The highest level of arterial pCO_2 with survival and without tracheostomy was 73 mm Hg in a man with a maximal breathing capacity of 18 L per minute before a left extrapleural pneumonectomy One year later his maximal breathing capacity was still 18 L per minute but his sputum and

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gastric washings proved negative on guinea pig inoculation His resting pulmonary arterial pressure was 35/15 mm Hg This pressure rose to 71/28 mm Hg on slight exertion

It may be difficult to obtain an arterial pCO_2 since the laboratory is often not functioning at the time when the decision has to be made Experience and clinical judgment alone however, are sufficient for the decision We have never had to regret that a tracheostomy was performed, only that it was performed too late

The best function test postoperatively is direct measurement of the arterial pO_2 and pCO_2 A low pO_2 with normal pCO_2 may indicate a secretion retention with atelectasis and shunting of blood through nonventilated alveoli Then repeated aspiration has to be done, if necessary, through a tracheostomy

If, on the other hand, pCO_2 is very high this is due to a ventilatory insufficiency and tracheostomy has to be performed immediately If the pCO_2 still is high artificial ventilation has to be added

3 *Artificial ventilation* through the tracheostomy is the last resource when the patient's own ventilation through the tracheostomy is insufficient The tracheostomy cannula is then provided with a rubber cuff to make an airtight connection with the respirator

We have used prolonged artificial ventilation postoperatively in two different groups of patients

A In one group of patients there has been a complication with an acute extensive infiltration in the only functioning lung During artificial ventilation and intensive antimicrobial therapy the pneumonias cleared up and the patients could take over the ventilation themselves (Cases 1 and 2)

B In the other group one patient had a compensated ventilatory insufficiency before the operation Only destroyed nonfunctioning parts of the lung were removed Then immediately after the operation a tracheostomy was performed and the patient intermittently kept on artificial ventilation

In these cases with abnormal functioning lungs a careful control in the arterial blood of the carbon dioxide tension of the pH and the carbon dioxide content (plasma) is necessary both for proper indications to tracheostomy and artificial ventilation and for adjustment of the artificial ventilation When the patient gradually gets stronger after a comparatively serious operation he can for increasing periods of time take over the respiratory work himself

METHOD

The artificial ventilation is performed through a cuffed silver cannula applied through a tracheostomy (modification of the method described by Lassen[1]) It is important that the tracheostomy is placed as high as possible (second to fourth tracheal cartilages) otherwise it is difficult to obtain an airtight connection using an ordinary cannula with an inflatable rubber cuff This rubber cuff must be placed near the distal end of the cannula or it will slip out through the tracheostomy (Fig 1) The rubber cuffed metal cannula is preferred to a cuffed rubber tube which may be dislocated down in the right main bronchus causing atelectasis and retention of secretion in the left lung Furthermore a rubber catheter may cause pressure necrosis with esophagotracheal fistula if it does not have enough curvature

These details in technique are important in order to obtain an airtight connection through the tracheostomy (Fig 2) The connection must be air tight if it should be possible to take over the ventilation of the patient completely If there is a considerable leakage around the cuff of the cannula (more than 2 L per minute) and the insufflated air oxygen mixture to a large extent goes backward up into the pharynx, the patient will have difficulty in synchronizing his breathing with the machine

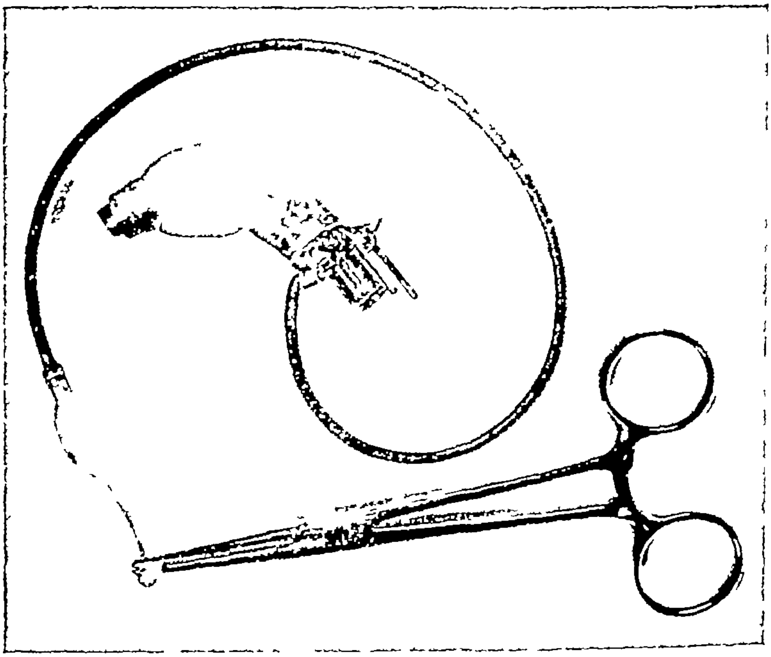


Fig 1 —The rubber cuff must be placed near the distal end of the cannula otherwise it will slip out through the tracheostomy

The artificial ventilation is administered by a special device designed and presented by Engstrom in 1951[10, 19] (Fig 3) In the last years it has come into widespread use for the treatment of severe cases of respiratory paralysis in poliomyelitis[1, 6-11] Principally this unit operates by direct insufflation into the air passages and is different in an important aspect from the usual types of positive pressure breathing devices All of the more common ones are either time or pressure cycled and operate to deliver a certain pressure This unit, when used with a tracheostomy tube or mask is volume cycled, i e, it delivers a preset volume In order to deliver this volume the pressures are different from individual to individual and often in the same individual from time to time depending on variation of the mechanical factors of the pulmonary ventilation[15, 16] The pressure fluctuations, which can be observed by

Fig. 2.—It is important to obtain an airtight connection through the tracheostomy

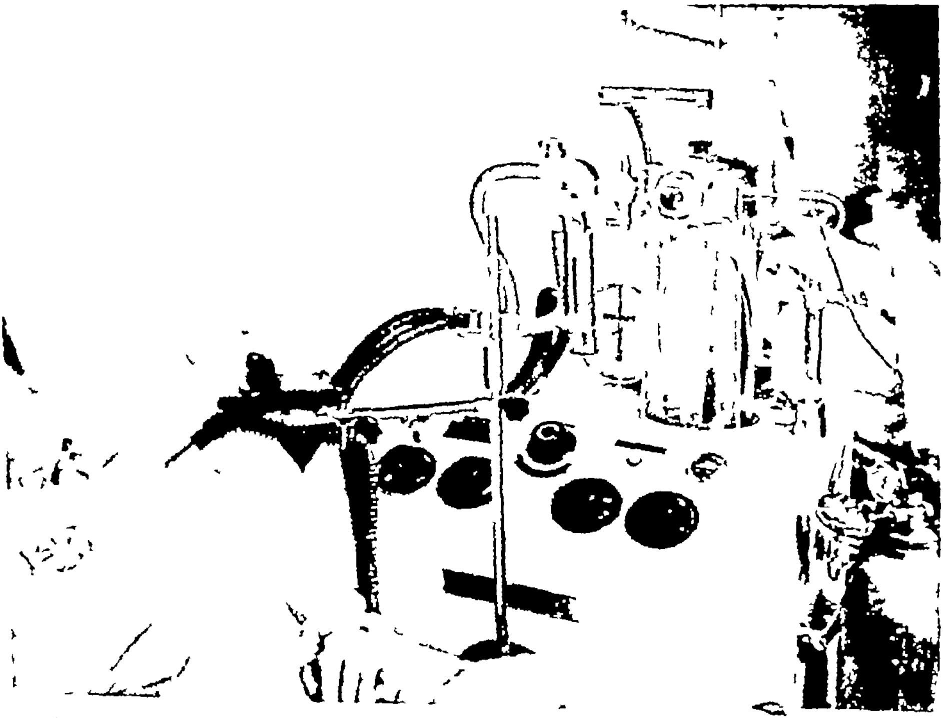


Fig. [illegible]—The patient [illegible] connected to the special device for artificial ventilation watching the column of air in a water lock, depend on the elastic properties of the lungs and thorax wall and the frictional tissue and airway resistance An increase of the pressure required to force a given volume of air into the patient's lungs is thus an indication of altered pulmonary mechanics and corresponds to increased respiratory work[8] in spontaneous respiration A maximal pressure can be set by changing the water level in the water lock so that dangerous pressures can be avoided A vacuum pressure capable of being regulated can be applied in the airways during the expiratory phase in order to keep the mean mask pressure and thereby the mean intrapleural pressure on low values so as not to impede the venous return and cardiac output during the insufflation breathing

We have found it adequate in these cases to use a gas mixture of 50 per cent oxygen and 50 per cent air The gas mixture is highly humidified, which is of importance during prolonged artificial ventilation through a tracheostomy Naturally frequent aspirations through the tracheostomy have to be made as long as secretion accumulates

These patients require a very careful supervision during the treatment When the patient improves after the intensive antimicrobial therapy he can at intervals be disconnected for spontaneous respiration for increasing periods of time In cases with poliomyelitis it has been possible to utilize this method with tracheostomy and artificial ventilation continuously for more than one year

In cases with normally functioning lungs and no metabolic acid base disturbances it is possible to calculate the adequate alveolar ventilation fairly accurately[6]

In cases with extensive lung infiltrations or lung parenchyma otherwise diminished in function, the adequate ventilation cannot be calculated It is therefore necessary to check the ventilation especially by analysis of the arterial blood (arterial carbon dioxide tension, blood pH, plasma CO_2 content) In the venous blood it is of value and very easy to follow the CO combining capacity (determined as alkaline reserve) which if it increases indicates hypoventilation compensated by retention of alkali ions[12]

In patients with hypoventilation receiving oxygen, the ventilatory insufficiency may be masked and carbon dioxide retention may be caused[9] This will result in retention of alkali ions in the blood with increasing carbon dioxide-combining capacity as a compensating mechanism for preventing respiratory acidosis with decreased blood pH The hydrogen-ion concentration of the blood is regulated by the relation expressed by Henderson Hasselbalch's formula[17]

$$\text{Blood-pH} = \text{pK}' + \log \frac{(\text{BHCO}_3)}{(\text{H}^{\cdot}\text{HCO}_3)}$$

(pK′ = a constant 6 107 at 37° C)

One must therefore be careful not to hyperventilate a case with high carbon dioxide combining capacity Hyperventilation may result in a rapid displacement of the blood pH to the alkaline side with disturbances in the balance of electrolytes, resulting in tetanus and coma

It may be emphasized that a dangerous hypoventilation may be masked and misunderstood when the patient receives oxygen until carbon dioxide has accumulated to such an extent that it will no longer act as a drive on the respiratory center[14] A clinical sign often observed is increasing blood pressure The patient then easily goes over in an uncompensated respiratory acidosis with rapidly decreasing blood pH, coma and circulatory failure A patient therefore should not be given oxygen when suspected of having an insufficient spontaneous ventilation, for instance, when he is taken from the respirator If he cannot be without oxygen the artificial ventilation has to be continued, or the arterial pCO_2 has to be checked A practical method is to determine the patient s minute ventilation at rest preoperatively If then the same volume per minute is used for ventilation during the operation as well as in postoperative period there is only a negligible danger of displacement of the pH to either the acid or the alkaline side

CASE REPORTS

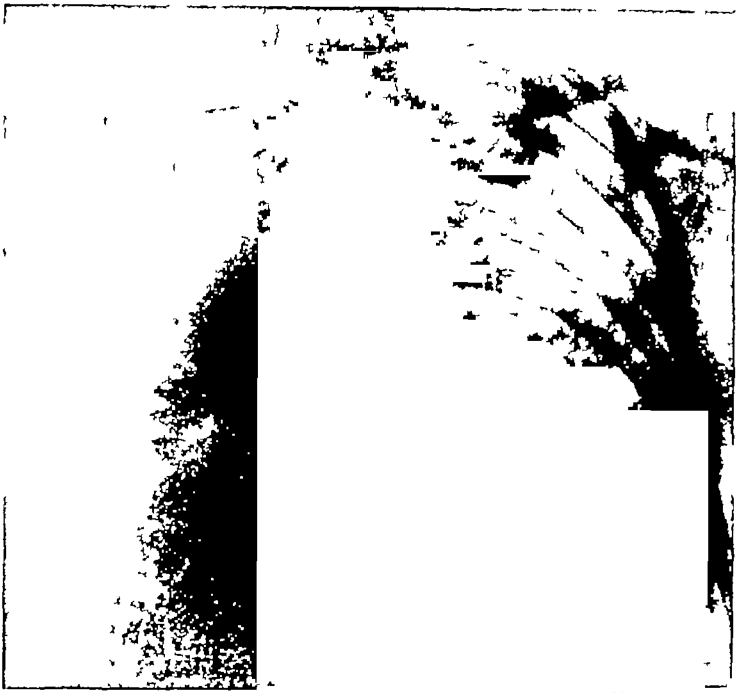
CASE 1 —A 36 year old man had cavitary tuberculosis in the right upper lobe and underwent a 7 rib thoracoplasty with apicolysis in 1949 A residual cavity remained in the right lung which had 21 per cent of the oxygen uptake The maximal breathing capacity was 91 L per minute At operation, the right upper lobe, the superior segment and the posterior basal segment of the right lower lobe, were resected under the thoracoplasty The phrenic nerve was divided during the extrapleural dissection of the lung The patient had difficulty in raising sputum from the right bronchial tree, which filled up with secretion causing a spill over with extensive infiltration in the only functioning left lung (Fig 4) On the fourth day after operation tracheostomy was performed and artificial ventilation instituted with 6 L oxygen and 6 L air per minute at a rate of 22 respirations per minute During the first days the respirator could only be disconnected for a few minutes when intratracheal aspiration was performed On the fifth day the artificial respirator could be disconnected for thirty minutes and after six days in the respirator when the infiltrations in the left lung had disappeared the patient was able to adequately ventilate himself through the tracheostomy When the respirator was first connected the systolic blood pressure dropped from 150 to 100 mm Hg The carbon dioxide accumulation made the patient comatose perspiring and in spite of a high blood pressure and the extremities were cool and cyanotic After one day in the respirator a normal peripheral circulation was restored A month later the patient could return to the sanatorium in a good condition (Fig 5)

CASE 2 —A [illegible] year old man had bilateral pulmonary tuberculosis and was treated with bilateral pneumothorax from 1940 to 1942 In 1954 a cavity in the left upper lobe was detected and surgery was advised Maximal breathing capacity was 79 L per minute The residual capacity was [illegible] per cent of the total capacity Bronchospirometry showed 50 per cent oxygen uptake by the left lung At operation a resection of the apicoposterior segments of the left upper lobe and of the superior segment of the lower lobe was performed The operation was completed with a decortication of the lower lobe and an osteoplastic thoracoplasty

On the second postoperative day an extensive infiltration was visible on the right side and there was atelectasis on the left side (Fig 6) Artificial respiration was carried out continuously for nine days when the infiltration was resolved and the patient's spontaneous respiration was sufficient The patient left the hospital in good condition (Fig 7)

CASE 3 —A 43 year old woman had a tuberculous cavity in the left upper lobe treated by [illegible] thoracoplasty in 1940 In 1951 there was a cavity in the right upper lobe In [illegible] the patient had been in hospital for two years and required an operation in spite

Fig 4



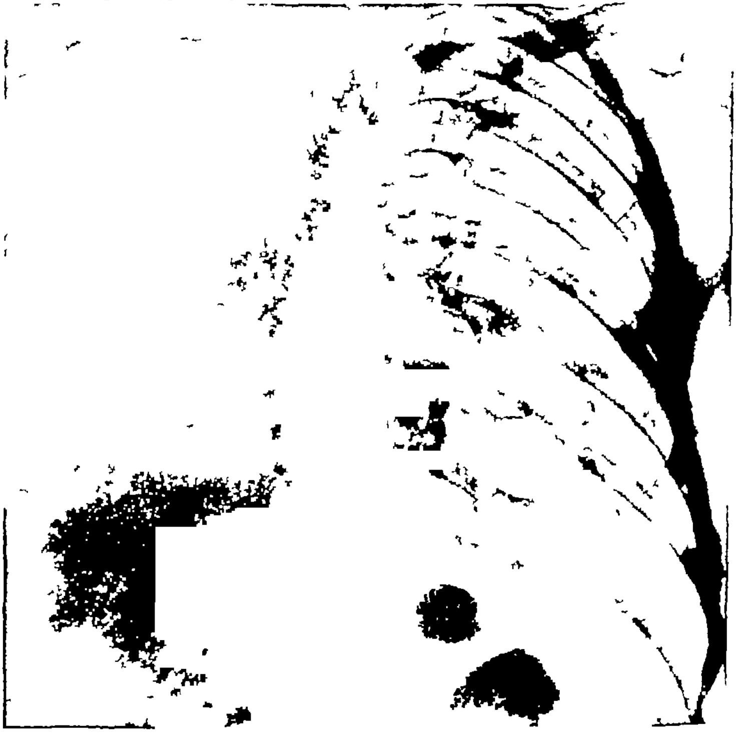
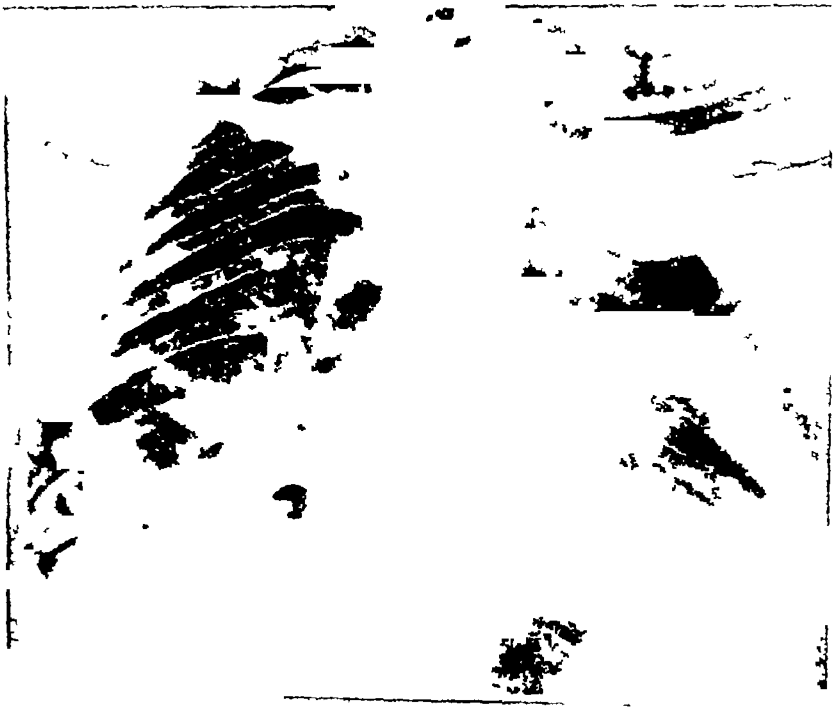


Fig 5

Fig 4 —*Case* 1 X ray demonstrating an extensive *infiltration in the only* functioning lung the left

Fig 5 —Case 1 X ray one month later when the lungs had cleared up and the patient could leave the hospital

Fig 6



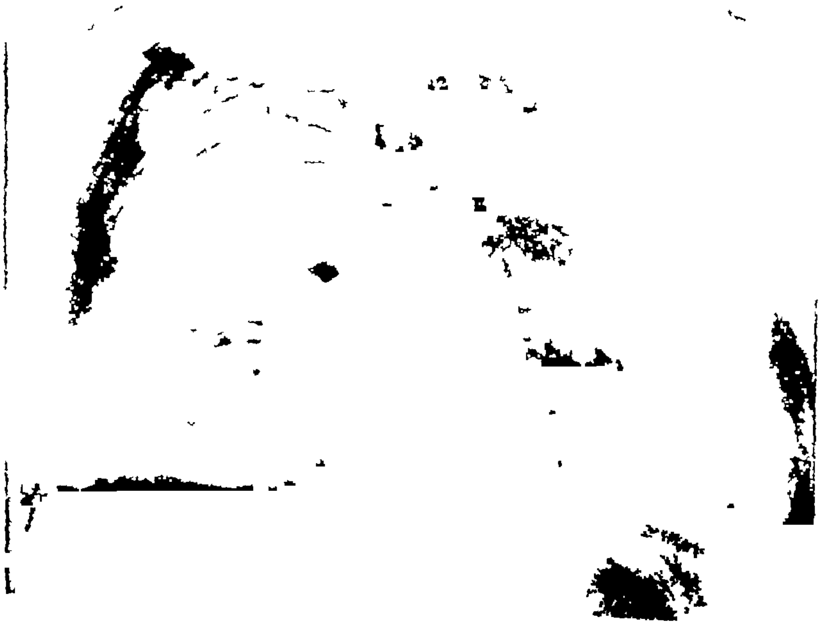


Fig 7

[illegible] X-ray demonstrating atelectasis [illegible] left [illegible] and extensive infiltration [illegible] right lung [illegible] bilateral infiltrations. The [illegible] later the lungs had cleared up and the patient could leave

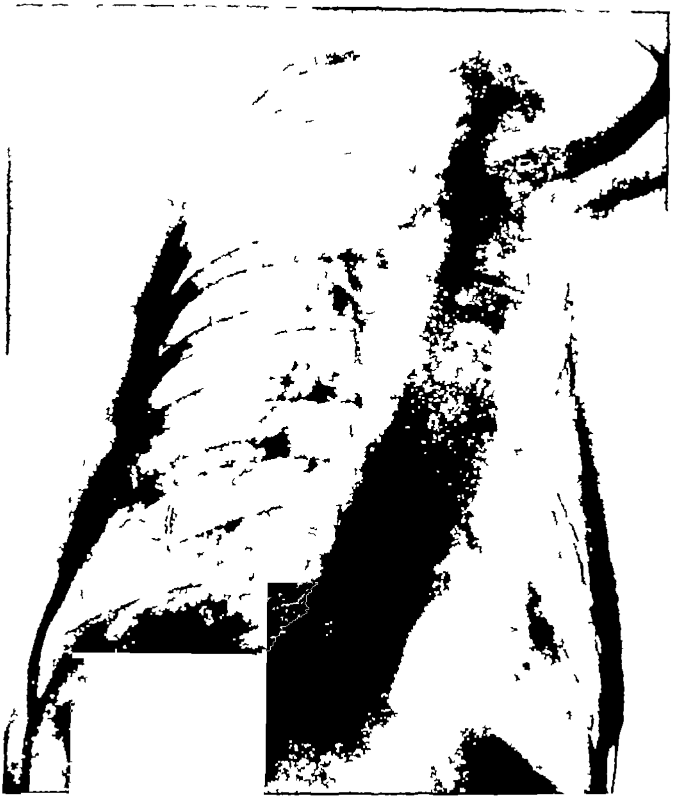


Fig 8—Case 3 X-ray demonstrating a left 8 rib thoracoplasty with only 11 per cent oxygen uptake on the left lung On the right side both upper and middle lobes were destroyed by cavitary tuberculosis.

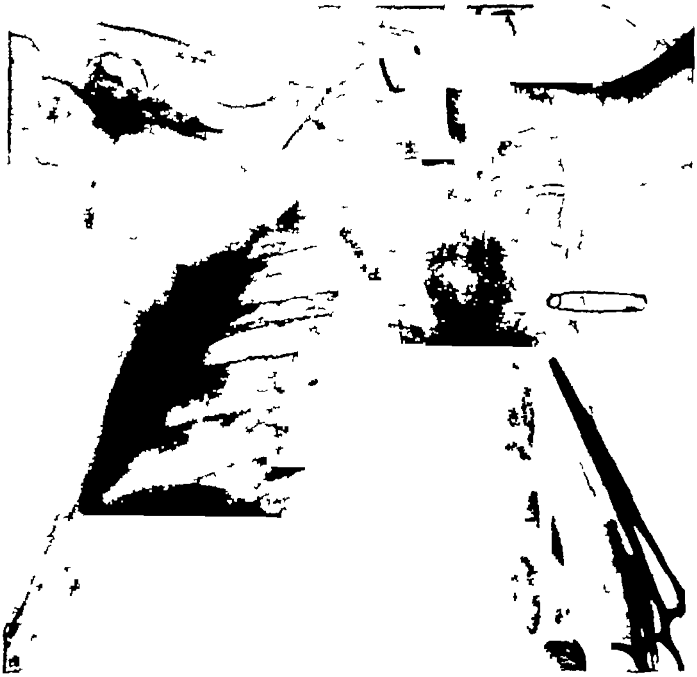


Fig 9—Case 3 X ray of the patient two weeks after operation She could then be without artificial ventilation 8 hours a day and walk a few steps

of the bad pulmonary function The maximal breathing capacity was 33 L. per minute The arterial oxygen tension was 75 5 mm Hg the pCO_2 was 37 3 mm Hg.[19] Bronchospirometry showed only 11 per cent oxygen uptake on the left side (Fig 8) At operation both upper and middle lobe on the right side were removed as well as a wedge of the lower lobe The lung tissue was completely destroyed and without function An osteoplastic thoracoplasty completed the operation Thus the patient had practically only one functioning lobe She was left with intermittent artificial ventilation One night when breathing spontaneously with oxygen she received a small dose of morphine causing hypoventilation and respiratory acidosis The accumulated carbon dioxide was masked by the oxygen therapy The alkali reserve was as high as 113 vol per cent Artificial ventilation then caused an alkalosis with tetanus and coma The pH was 7 55 with a carbon dioxide combining capacity of 114 vol per cent pCO_2 = 62 mm Hg Intravenous NH_4Cl KCl, blood "aminoglycose" and serum albumin was given and the blood pH and pCO_2

Fig 10

had to be followed to bring the patient back in normal electrolyte balance during con[illegible] ventilation Two weeks after operation she could breathe spontaneously [illegible] and after three weeks the respirator was not needed any longer [illegible] condition (Fig 10)

DISCUSSION

Postoperative complications with acute infiltrations in the only functioning lung are very dangerous We have seen two such patients recover even [illegible] tracheostomy But we have also seen a few patients die with ventilatory insufficiency due to extensive infiltrations in the only functioning lung The patients described here would undoubtedly have died without prolonged artificial ventilation

In cases with an acute extensive infiltration in the only functioning lung the patient has been kept on artificial ventilation continuously for about one week During this time intensive antimicrobial therapy was given because of the pneumonia which gradually resolved Two such patients were so treated They were in a serious condition when the artificial ventilation was instituted If they were without artificial ventilation for one to two minutes, they turned deeply cyanotic due to insufficient gas exchange through the lungs The disturbance of the pulmonary gas exchange in these cases depends on perfusion through unventilated pneumonic areas and considerable decrease of ventilated alveoli

The decrease of ventilated alveoli will cause (a) decreased diffusion surface necessitating a considerable hyperventilation, (b) unfavorable mechanical factors for respiration with decreased lung compliance and probably an increased tissue frictional resistance

These factors acting in the same direction will result in a highly increased respiratory work for a sufficient ventilation Our patients could not perform this high respiratory work The mechanical factors could be followed on the pressures during insufflation, which in the beginning showed high values which diminished when the infiltrations cleared up When the pneumonias were resolved, the mechanical factors of respiration were improved and the patients could then rapidly take over the ventilation

Another possibility discussed in this situation is an extracorporeal oxygenation of the blood with an oxygenator pump A clinical case of cor pulmonale was treated for 75 minutes with an oxygenator pump by Helmsworth and co-workers Dyspnea improved and cyanosis was sharply reduced during the performance Such an apparatus, however, cannot be connected long enough for the healing of a pneumonia Furthermore, the heparinization of a patient who has undergone a major thoracic operation is contraindicated The prolonged application of artificial ventilation by the method described, however, has proved lifesaving to patients with serious complications and ventilatory insufficiency after pulmonary resection Altogether 15 patients have been treated and there has been only one death and that has been due to the fact that the artificial ventilation was instituted too late Our series included one man with a right pneumonectomy performed earlier on whom the apicoposterior and inferior lingula segments of the left upper lobe have now been removed In another case, the right upper lobe, the left upper lobe, and the superior segment of the left upper lobe were removed with a left sided osteoplastic thoracoplasty performed in one stage in the prone (Overholt) position In a third case with tuberculosis and mitral stenosis, an insufficiency was obtained after commissurotomy This patient received artificial ventilation with expiratory resistance In the other cases, a negative expiratory phase was utilized. The patients can receive more morphia and have a smoother postoperative course

SUMMARY

Principles of treatment of postoperative ventilatory insufficiency are outlined Two patients with extensive infiltration in the only functioning lung were saved by six days treatment with artificial ventilation (Engström respirator) With intensive antimicrobial therapy the lung cleared up and the patients recovered Postoperative artificial ventilation is also used intermittently or continuously in cases of highly diminished ventilatory capacity

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ESOPHAGEAL RECONSTRUCTION BY MEANS OF PROSTHESIS

EXPERIMENTAL AND CLINICAL EXPERIENCE

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INTRODUCTION

THE modern surgical treatment of cancer of the esophagus often involves the rather extensive resection of the neoplasm with its adjacent lymphatics and subsequent anastomosis of the proximal esophagus to the stomach, jejunum, or colon Those of us who have assumed the responsibility of treating this disease have sought for some time for a less formidable procedure which might be used when the clinical or operative evaluation of the patient establishes that the tumor cannot be completely resected or where the general condition of the patient has so deteriorated that an extensive procedure does not seem feasible

From the classical work of Neuhof[1] in 1917, it is apparent that fascia lata may be used as a framework for the epithelization of small defects in the esophagus In this article Neuhof stated that "transplanted fascia has remarkable viability even under the most disadvantageous conditions " He was the first to demonstrate that a fascial graft could be satisfactorily employed to repair a defect in the wall of a hollow viscus Taffel[2] later used similar grafts in defects of the trachea with equal success Grindlay[3] and his associates demonstrated the feasibility of using polythene tubes to replace excised portions of tubular structures, namely, the common bile duct, trachea, and colon Berman[4] recently reported the use of polythene tubes alone to replace excised segments (40 to 96 mm) of the esophagus of dogs He reported successful results in 13 of the 20 dogs used No attempt to cover the tube with living host tissue was described by him Klopp and co-workers[5] have used polythene film with split thickness skin grafts both in the reconstruction of the cervical esophagus and for pharyngeal defects

It is the purpose of this paper to review our experimental and clinical results, using polythene plastic tubes covered with fascia lata or split-thickness skin grafts as a replacement for resected segments of the esophagus

EXPERIMENTAL RESULTS

Using 20 mongrel dogs, 2 inches of the middle third of the thoracic esophagus was excised and replaced by an esophageal prosthesis This prosthesis was constructed by means of an autogenous fascial sleeve over a semirigid polythene tube splint

Procedure —In 18 of the dogs a fairly standardized procedure was followed The prosthesis was constructed by suturing fascia lata from the thigh of the animal into a 2

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inch sleeve around the polythene tube splint using a No 5 0 running silk suture. The polythene tube was of fairly rigid construction, 2½ to 4 inches long with an inside diameter of ½ inch and a wall thickness of 1 mm. One to 2 cm from each end of the tube a ringlike flange projected about 1 mm from the outer surface (Fig 4). Through a right transpleural approach the esophagus was isolated in its middle third and a 2 inch segment resected. The previously constructed prosthesis was then sutured into the defect and anchored in the lumen at the proximal end by two laterally placed mattress sutures passed through the polythene tube and all coats of the esophagus. The free edges of the fascial sleeve were then sutured to the cut ends of esophagus proximally and distally with a running No 3 0 chromic suture. The chest was closed in layers and the pneumothorax was evacuated as the closure was completed.

Postoperatively the animals received intravenous fluids for three days and oral fluids for three days progressing to a full liquid diet. Prophylactic antibiotics were given for one week.

TABLE I ESOPHAGEAL PROSTHESIS

CAUSE OF DEATH	NO OF ANIMALS
Fascial slough	7
Anesthesia	1
Technical error	1
Pneumonia	1
Malnutrition	6
Sacrificed	2

Results—In analyzing our results (Table I) a two-week period was used to determine operative versus nonoperative mortality. This period was chosen as it was noted that the fascial graft sloughed as late as twelve days postoperatively leading to pyopneumothorax and death. On this basis our operative mortality was 50 per cent or 9 dogs. In 7 of the 9 dogs, the cause of death was a clear-cut slough of the fascia with resultant esophagopleural fistula. One animal died from a leak at the esophagofascial anastomosis and another death was attributed to anesthesia. In the animals in which a fascial slough occurred the disaster occurred from 2 to 12 days postoperatively averaging 6 to 7 days. As intercostal drainage was impractical the esophagopleural fistula resulted in rapid death. The fascia invariably showed separation of the frayed and necrotic fibers near the midpoint of the graft with the fibers at either end nearest the esophagofascial anastomosis showing the best survival. It is also of note that although nearly all of the lateral retention sutures eventually pulled through the esophageal wall leaving the tube free there was no evidence of leak at this site.

Nine animals (50 per cent) of the 18 survived the 14 day postoperative period living an average of 51 days varying from 18 to 128 days. Two animals were sacrificed at 107 and 128 days postoperatively. Malnutrition was a major problem in 6 of the 9 survivors due to refusal or inability to eat. In 4 animals there was definite mechanical obstruction in the form of rapidly developing strictures following migration of the plastic tube from the graft site. Three tubes were carried into the stomach and one migrated anteriorly forming an abscess cavity anterior to the esophagus (Fig 1). Two malnourished animals showed no evidence of obstruction but merely refused to eat. Both animals died of a complicating pneumonia.

Three animals maintained an adequate nutritional state, but 1 of these also died of a complicating pneumonia The remaining 2 animals were sacrificed at 107 and 128 days One of these 2 animals had regurgitated the plastic tube 32 days prior to sacrifice and showed very definite stricture formation at the graft site (Fig 2)

The over-all mortality due to both operative and postoperative complications was 89 per cent with only 2 animals having a relatively uncomplicated course

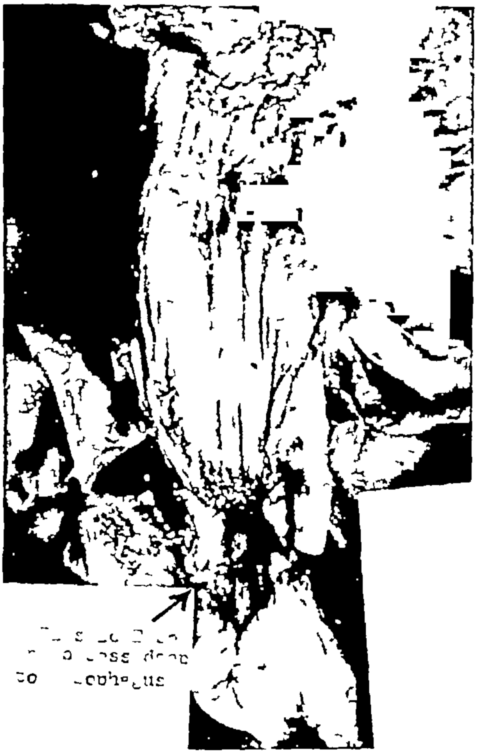

Fig 1

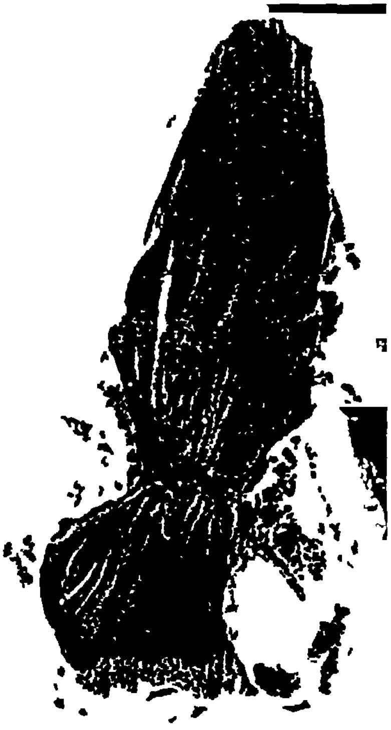

Fig 2

Fig 1—Experimental autopsy specimen (Dog No 547) shows prosthetic tube which migrated anteriorly to lie in abscess cavity between esophagus and heart.

Fig 2—Experimental autopsy specimen (Dog No 639) shows stricture formation in graft site at time of sacrifice 32 days following removal of tube Epithelium has completely covered the graft.

Separate consideration is given to 2 animals in which the aforementioned procedure was varied In these animals, the tube was tied in place with a purse string suture supported by a heavy ligature around the esophagus and tube proximally and distally The fascia was then sutured to the muscular coat of the esophagus beyond the ligatures as an onlay graft, thus excluding it from food stream contamination As might be expected, the blood supply to the graft was inadequate which resulted in a slough of the graft and esophagus beyond the ties Continuity was disrupted and both animals died rapidly This procedure was abandoned for obvious reasons

Microscopic Findings.—Microscopic sections were made of the grafts and revealed several significant findings.

In only 1 case was there complete coverage of the graft by epithelium. This occurred in the animal that regurgitated the tube on the seventy-fifth day with sacrifice 32 days later. In 3 other cases there was minimal growth of epithelium from one end of the graft varying from scattered minute islands to a cuff ¼ inch in extent. In the remaining 5 survivors there was absolutely no epithelization and in fact 2 showed loss of epithelium along the adjacent esophageal surface. This suggests that the presence of the plastic tube is somewhat disadvantageous to epithelization, probably on the basis of mechanical irritation.

There was a consistent severe cellular inflammatory reaction in the fascia and surrounding structures. Also noted was a marked fibroblastic reaction surrounding the fascial graft with necrosis and slough of the superficial graft fibers and distinct hyalinization of the deeper fibers. This raises the question as to whether the fascia survives, is replaced by new fibrous tissue or acts as a temporary barrier to the food stream while the surrounding tissue reaction provides the permanent structure.

The grafts which definitely sloughed showed complete hyalinization of fibers and similar inflammatory responses.

The most obvious important conclusion to be drawn from this experimental study is that, at best, our results with this procedure are not good in the dog. An operative mortality of 55 per cent when combined with the fact that in 50 per cent of the series death seemed directly due to failure of the fascia to survive seems to preclude any other conclusion. The fascia lata apparently could not withstand the insult of constant contamination by the food stream. The graft could not be separated from the food stream without compromising the main source of blood supply through the esophageal wall. In support of this it was noted that the slough in 9 of 10 dogs occurred at midgraft rather than at the anastomosis. Second, in the cases where attempt was made to exclude the graft from the food stream by ligatures around the esophagus the fascia distal to the ligature sloughed.

Use of this type of procedure in the human being might yield better results than our experimental results would indicate, with intercostal drainage and gravity as an aid in the mechanism of swallowing, but several basic defects in the prosthesis would militate against long term successes. The microscopic and gross evidence of the failure of the autogenous fascia to survive as an intact tube, the lack of epithelization in the presence of the plastic tube and rigid structure without the plastic splint indicate that a split thickness skin graft might be preferable. A more flexible plastic tube which will still maintain a lumen might avoid the erosion of adjacent structures such as aorta and trachea.

CLINICAL MATERIAL

Case 1.—G. F. A., No. 7-19[illegible], a [illegible]-year-old white man was referred to the Roswell Park Memorial Institute in July 1951 with a five month history of dysphagia, weakness and [illegible] and esophagoscopic studies revealed an ulcerating obstructing carcinoma of the esophagus, 19 cm. from the incisor teeth. General medical survey revealed hypertension, auricular fibrillation, and generalized arteriosclerosis, indicating the rather poor general condition of the patient

After the usual preparation, an operation was performed on Sept 4, 1951 The cervical esophagus and proximal portion of the lesion were mobilized through an incision along the anterior border of the right sternocleidomastoid After this stage of the operation was completed, the right chest was entered through the bed of the fourth rib, in order to explore the extent of disease The remaining distal portion of the lesion was then mobilized The esophagus was transected distal to the lesion and the plastic tube fitted into the lumen of the distal transected end of esophagus Interrupted black silk sutures were placed through both the wall of the esophagus and the rim of the plastic tube to anchor the tube in place

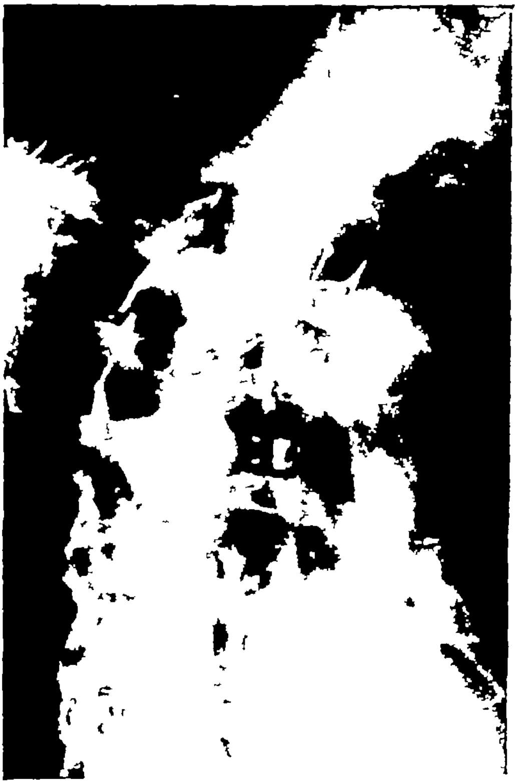

Fig 3 —Esophagogram done on clinical Case 1 shows tube prosthesis in place with food stream passing around plastic tube.

The tube was then covered with mediastinal pleura A drain was inserted into the mediastinal space and brought out through a stab wound posteriorly with intercostal drainage through the eighth interspace The chest was closed, and the esophagus then delivered *into the* cervical wound and transected 2 cm proximal to the lesion The plastic tube was placed into the lumen of the proximal transected esophagus and sutured in place with fine silk The neck wound was closed in layers with a drain inserted into the mediastinum A Witzel type gastrostomy was performed for feeding purposes

The postoperative course was uneventful Oral feeding was started gradually, and by the fourth postoperative week the patient was eating puréed foods satisfactorily (Fig 3) He was discharged on the thirtieth postoperative day in good condition

On Dec 1, 1951, three months after surgery, the patient was admitted because of dyspnea which developed rather suddenly Bronchoscopy revealed obstruction of the trachea due to pressure posteriorly Before an emergency operation could be performed to remove the tube the patient died An autopsy revealed the plastic tube in the position in which it was placed at time of surgery Marked congestion and partial obstruction of the trachea were present adjacent to the tube The transected ends of the esophagus were closely applied about the edges of the tube with evidence of epithelization over the ends of the tube Residual carcinoma was present but the immediate cause of death was due to tracheal obstruction caused by the pressure of the plastic tube (Fig 4)

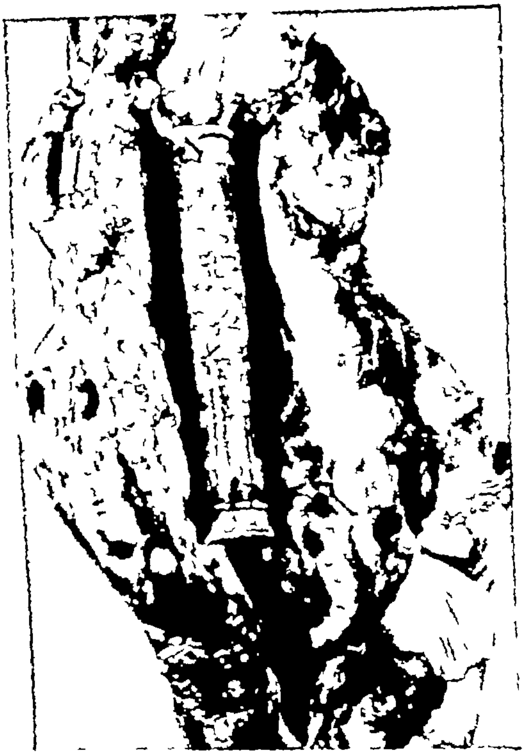

Fig 4 Autopsy specimen clinical Case 1 shows tube in place with epithelium forming over the end of the tube and surrounding tumefaction

Case 2 — L G A (No 72821) a 60 year old white man was admitted to Roswell Park Memorial Hospital in September 1951 with a five month history of dysphagia and a weight loss of 25 pounds Esophagograms and esophagoscopy revealed an obstructing carcinoma at the junction of the upper and middle thirds of the esophagus After the usual preoperative preparation with high caloric liquefied diet and transfusions, an operation was performed on Oct 15 1951

The abdomen was explored in order to mobilize the stomach Exploration revealed a large mass of firm carcinomatous lymph nodes surrounding the celiac axis Primary resection of the esophagus was not feasible because of this finding and the abdomen was closed

The patient was placed on his left side and a split thickness skin graft taken from the right thigh The right chest was opened revealing a freely movable lesion at the level of the [illegible] The esophagus was mobilized and transected 4 cm above and below the [illegible] The [illegible] was then removed and a plastic tube placed in the bed [illegible] portion of esophagus was sutured to the distal and proximal ends of esophagus [illegible] the skin graft with its areolar surface facing the mediastinum was [illegible] the plastic tube and sutured to the proximal and distal ends of esophagus

The mediastinal pleura was closed. A No. 18 catheter was placed within the mediastinum emerging through the chest wall posteriorly in the sixth interspace and additional intercostal drainage instituted. The chest was closed in layers.

The postoperative course was uneventful except for persistent drainage from the catheter. A Stamm gastrostomy was performed for feeding purposes, and by the fourth postoperative week the patient was taking oral feedings satisfactorily. The esophago-cutaneous fistula closed six weeks after surgery, and the patient was discharged on the sixtieth postoperative day in good condition.

During the next three months the patient remained in good condition, being able to swallow chopped meat and vegetables without significant difficulty. Five months after surgery dysphagia recurred. A barium study suggested recurrent carcinoma at the distal end of esophagus near the tube, but the patient refused to have any further diagnostic or operative procedures (Fig. 5). For the next two months his condition remained static. He continued to swallow liquid foods without difficulty. However, in the seventh postoperative month the dysphagia became progressively worse. He was admitted to the hospital nine months after the surgical procedure in very poor condition and died in a few days.

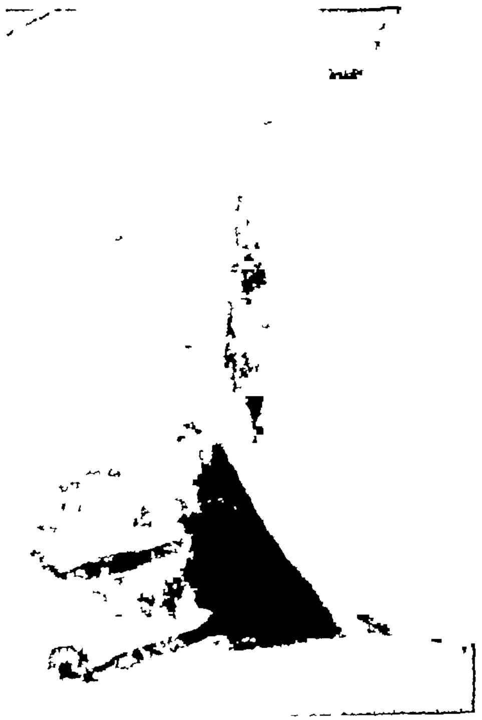

Fig. 5.—Esophagogram on clinical Case 2 postoperatively shows passage of food stream through tubes.

On autopsy, the plastic tube was found lying free in the lumen of the esophagus. Recurrent carcinoma was found in the esophagus at the distal line of resection with almost complete obstruction, but at the proximal line of resection there was complete continuity between the esophageal mucosa and the skin graft. About the celiac axis, a large mass of metastatic tumor was found.

CASE 3.—T. M. (74550), a 67-year-old white man, was admitted to the Roswell Park Memorial Institute in April, 1952, with a seven-month history of dysphagia, loss of 15 pounds and a one-and one half month history of pain in both sides of the neck after eating. Esophagograms and esophagoscopy revealed a partially obstructing carcinoma in the middle third of the esophagus.

After preoperative preparation with high caloric liquefied diet an operation was performed on April 29 1952

Through a right transpleural approach the esophageal lesion was identified in the middle one third of the esophagus The lesion had eroded through the wall of the esophagus and was visible as a massive ulcer crater penetrating the entire wall with adherence of the lesion to the thoracic aorta. After mobilization except where the tumor was adherent to the aorta. the lesion was resected with approximately 2 cm. of esophagus above and below the gross involvement A portion of tumor along the aorta remained in situ A plastic tube was then placed in the bed of the excised portion of esophagus and four stay sutures of No 0 black silk were placed through the wall of esophagus and rim of the tube on each end to anchor the tube in place A purse string suture was placed in the wall of the esophagus 1 cm. from the transected ends and drawn tight to seal the esophagus around the tube. The parietal pleura was freed from the thoracic wall and reflected over the tube to pleuralize the operative area and a rubber drain was placed near the tube and brought out through the posterior chest wall Intercostal drainage was instituted and the chest wall was closed in layers A Stamm gastrostomy was then performed through a short upper left paramedian incision for feeding purposes

The postoperative course was uneventful and the patient was discharged on the thirtieth postoperative day taking pureed foods orally without difficulty One week after discharge he suffered a severe gastrointestinal hemorrhage at home and was readmitted June 6, 1952 Transfusions were given but one week later he had another severe hemorrhage and succumbed

At autopsy the plastic tube was still in place but a penetrating ulcer 1 cm in diameter was found in the upper transected end of the esophagus which appeared to be the source of the hemorrhage The esophagus and stomach were filled with blood clots Mediastinal lymph nodes contained metastatic carcinoma and a large mass of tumor was found along the thoracic aorta The immediate cause of death was hemorrhage due to ulceration of the esophagus proximal to the prosthesis apparently due to mechanical pressure by the plastic tube

CASE 4—A H (No [illegible]) a 72 year old white man was admitted to the Roswell Park Memorial Institute on March 1[illegible] 1952 with a five-month history of dysphagia Physical examination was not remarkable Esophagoscopy and esophagograms revealed a constricting carcinoma in the middle third of the esophagus Laboratory examinations were within normal limits and after preoperative preparation with a high caloric liquefied diet and transfusions an operation was performed on March 18 1952

A Stamm gastrostomy was performed following which the patient was placed in the left lateral decubitus position and the right chest was entered Using sharp and blunt dissection the esophagus was freed anteriorly from the bronchus and laterally from the arch of the aorta and descending aorta The entire tumor could not be removed because of attachment to vital structures After adequate mobilization the lesion was partially resected 2 cm. proximal and distal to the gross involvement The plastic tube was placed in the resected esophageal bed and sutured to the ends of the transected esophagus as previously described A strip of fascia lata which had been previously removed from the right thigh was wrapped about the tube and sutured in place as a sleeve onlay graft A straight No 16 rubber catheter was placed next to the operative site and was brought out of the chest posteriorly Additional intercostal drainage was instituted and the chest was closed

The postoperative course was fairly uneventful for the first four weeks but after oral feedings were instituted a small empyema cavity developed in the right thorax which was treated by open drainage Lipiodol studies two months after surgery revealed a tracheo esophageal fistula The gastrostomy was reconstructed and the patient discharged on tube feedings in fair condition The patient died three months later at home, an [illegible]

COMMENT

This material both experimental and clinical has been reviewed for the primary purpose of outlining the personal experiences of the surgeons using this prosthesis for palliation of this disease It is indeed a trying situation when one finds a patient with an obstructive lesion of the esophagus for which either because of poor general condition or the failure of some important organ, one is faced with the improbability of being able to complete a satisfactory curative esophagectomy. Procedures suggested by others, such as esophagojejunostomy and esophagocologastrostomy, are operations of great magnitude in themselves, and the patient requires considerable physiological fortitude to withstand such a procedure. The problem that is most trying is exemplified by the lesion in the middle or upper third of the esophagus, where because of the extension of the lesion into the tracheobronchial tree or aorta complete resection is not possible. Moreover, one often sees patients who have limited reserve and who have lesions which may be resectable but which are combined with extensive metastatic nodes in the celiac axis or in the supraclavicular regions, and who are also suffering from complete obstructions. These patients deserve some consideration. It was largely because of these factors that we have looked for a method of treatment which might be of some use when all other measures seem impractical. Our experiences in the experimental laboratory with this problem have not been very satisfactory or even encouraging.

The 4 patients who were operated on in this manner tolerated the procedure satisfactorily and had varying amounts of palliation. One of these, J. A., had the most satisfactory palliation, being able to swallow both solid and fluid foods for about nine months. There have, however, been serious complications. We feel that the plastic tubes being used by us have perhaps been too rigid. They can be made more supple and flexible in the future so that they will not tend to erode large vessels or injure the posterior wall of the trachea. It is perhaps unwise to use plastic tubes which occupy more than half of the length of the intrathoracic esophagus. Specifically this would amount to a tube being limited to 5 inches or less. The curvature of the dorsal spine makes it extremely difficult to stabilize a tube of greater length properly and prevent it from injuring structures that cannot move out of the way easily. This method in our hands does not seem to merit a place in the armamentarium of the surgeon doing this type of work except as a last resort when lesions have been partially resected and continuity must be established quickly. The technique is simple, adequate drainage can be provided and some measure of palliation can be expected. This method cannot be proposed as an alternative in our experience for any of the known established methods of restoring continuity of the esophagus.

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5. Klopp, C. T., Alford, C., and Pierpont, H.: Use of Polyethylene Film and Split Thickness Skin Graft in Reconstruction of Cervical, Esophageal and Pharyngeal Defects, Surgery 29: 231, 1951.

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-sixth Annual Meeting of the American Association for Thoracic Surgery will be held May 7, 8 and 9, 1956, in Miami Beach, Florida. Headquarters will be at the Hotel Fontainebleau.

Requests for Hotel Reservations

These should be mailed directly to Mr. Jack Slone, Director of Sales, Hotel Fontainebleau, Miami Beach, Florida. Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure. If accommodations are desired elsewhere in Miami Beach, please communicate directly with the hotel of your choice.

Thoracic Surgical Forum

The Thoracic Surgical Forum will be continued as a special session at the 1956 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferral to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgical Forum papers will be published together in *one* issue of the JOURNAL. Maximum length 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of all papers at the 1956 meeting must be received on or before Dec. 15, 1955, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgical Forum," or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five repeat five copies of *each* abstract must be sent to the Secretary of the Association, Dr. Paul C. Samson, 3959 Happy Valley Road, Lafayette, California. They should not be sent to the Editor.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in the JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected [illegible]. *The* [illegible], together with descriptive material concerning [illegible] must be received by Dr. Julian Johnson, University Hospital, [illegible] before Dec. 15, 1955.

(Continued on next page)

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Assocation must be received by the Membership Committee not later than Dec 15, 1955, otherwise, the applications will be deferred for consideration until the 1957 meeting

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

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Original Communications

THE USE OF PRESSURE RECORDINGS OBTAINED AT TRANSTHORACIC LEFT HEART CATHETERIZATION IN THE DIAGNOSIS OF VALVULAR HEART DISEASE

Don L. Fisher, M.D.* (By Invitation)
Pittsburgh, Pa.

INTRODUCTION

SINCE the introduction of a method of transthoracic left atrium puncture by Viking Olov Björk[1] the procedure has been further adapted to include the insertion of a plastic catheter for access to the left ventricle and aorta.[2, 3] Once this access has been gained, studies of cardiac output, dye injection, intracardiac electrocardiography, angiocardiography, and pressure recording can obviously be applied as in right heart catheterization techniques. However, the principal use has been in the recording of pressures for the demonstration of the effects of valve lesions. Such pressure recordings may supply a need that sometimes cannot reliably be met by the many other diagnostic methods which are available.

This report of an initial series of 61 cases illustrates the use of left heart catheterization as a preoperative diagnostic test. Nearly all the patients had rheumatic valve disease with uncertain or atypical combinations of findings on auscultation, electrocardiography, and fluoroscopy. Diagnostic criteria for judging the pressure effects of specific valve lesions were derived from recordings of pressure in experimental lesions presented in the literature, from previous experience with direct recordings at thoracotomy,[4] and from recordings of the analogous tricuspid and pulmonic valve lesions observed at right heart catheterization (Table I).

METHODS

The 61 tests were applied to 9 outpatients and 52 inpatients. Premedication was given in the fasting state. Moderate sedation in the average adult was produced by the usage of pentobarbital 0.1 Gm. orally and meperidine

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[illegible] The American Association for Thoracic Surgery [illegible]

*[illegible] Hospital, Pittsburgh, Pa.

TABLE I TENTATIVE CRITERIA FOR DIAGNOSIS BY PRESSURE EFFECTS

	SEVERITY				
	0	1+	2+	3+	4+
Mitral Stenosis Effect—					
Left atrium mean pressure minus left ventricle early diastolic pressure (early diastolic pressure immediately follows the initial diastolic dip) (mm Hg)	0 3	4 6	6 10	10 15	15+
Mitral Insufficiency (or Incompetence) Effect—					
Left atrium V wave height, minus C wave height	0 3	4 6	6 8	8 10	10+
Aortic Stenosis Effect—					
Left ventricle systolic pressure, minus aorta or peripheral artery systolic pressure	±15	15 20	20 25	25 30	30+
Aortic Insufficiency—Not studied					
Left Ventricular Failure Effect—					
Left ventricle end diastolic pressure minus upper limit of normal (9 mm)	0	1 3	4-6	7 9	9+

hydrochloride, 100 mg , intramuscularly Limb electrodes were connected for continuous monitoring of the electrocardiogram on the cathode-ray oscilloscope An indwelling needle or percutaneous arterial catheter was placed in a peripheral artery, the lumen being kept free by intermittent flushing or with a blunt stylus In 6 patients, a right heart catheter was also placed, through an antecubital vein, for "pulmonary capillary" pressure determinations simultaneously with the direct left atrium pressures The patient was then turned to a prone position on the padded fluoroscopy table, and the skin of the back was scrubbed and draped The underside of the fluoroscope screen was draped with a sterile towel At a brief preliminary fluoroscopy, the appropriate skin site for needle puncture was chosen, directly opposite the position of the left atrium, using a hemostat for a pointer This was usually in the right seventh or eighth intercostal space, at a point 2 fingerbreadths (4 to 4½ cm) to the right of the spinous processes The skin and subcutaneous tissues were infiltrated with 4 c c of 1 per cent procaine, and then a 6 inch No 18T thin-walled styletted needle was inserted It was directed anteriorly, and inclined about 25 degrees obliquely to the left, so as to pass in front of the spine by a right paravertebral approach Contact with bone was avoided, in order to prevent periosteal pain

The position of the needle was checked fluoroscopically at a needle depth of 7 to 8 cm , and it was reinserted if necessary The left atrium was entered at a needle length of 10 to 14 cm Bright red blood then issued, or could be aspirated easily A blood sample was withdrawn for blood gas measurements If dark blood was aspirated, then right heart catheterization was first performed (three cases) The left atrium was then located, during either the withdrawal or reinsertion of the needle

Recordings of pressure were made directly from the needle, showing the contour of the atrial pressure curve at high sensitivity, using the Hathaway PS 8AI inductance gauge, with Sanborn strain amplifier and direct writing recorder The needle was repeatedly flushed with heparinized 0 9 per cent sodium chloride solution to prevent thrombus formation A plastic catheter* was next inserted to gain access to the left ventricle and aorta The pressure was monitored during this maneuver, and no attempt was made to visualize the catheter fluoroscopically Several recordings were made of the pressure transition during withdrawal of the catheter through the aortic and mitral valves If the aorta could not be entered, then recordings were made from the left ventricular position simultaneously with the peripheral artery recording from needle or catheter The intracardiac catheter and left atrium needle were then withdrawn, having been left in place 3 to 75 minutes (average 30 minutes) The pressure gauges were calibrated against mercury and water manometers Corrections were applied to the various pressure measurements so as to correspond with a zero reference level at the intra-atrial point of the needle Physical examination and chest films were repeated at twenty-four hours to detect possible complications

RESULTS

A comparison of the interpretations of pressure measurements with findings at operations and autopsies is recorded in Table II There was only one major disagreement in these respective diagnoses, using the criteria for the preoperative diagnosis as listed in the table

In the 6 patients who also had simultaneous right heart catheterization by the venous route, the pulmonary artery wedge pressure corresponded closely to the left atrial pressure in both pulse contour and mean pressure level in 3 cases It corresponded only with the mean pressure level and not in pulse contour in 3 cases

In 2 cases there was a definite anacrotic (upstroke) notching and delay on the brachial artery pressure recording, yet no systolic pressure drop was present across the aortic valve at left heart catheterization and no systolic aortic thrill was palpable at operation However in each case of aortic stenosis with systolic pressure drop across the valve there was some deformity of the brachial artery systolic peak

Complications occurred in Patients 1 7, and 14 of the series In Patients 1 and 7 the needle was first directed into the right hilum entering the pulmonary artery Minor fluid densities were seen later at the right bases on x-ray films At a thoracentesis on Patient 7 125 c c of blood was aspirated The asymptomatic hemothorax cleared spontaneously thereafter in each of these 2 cases In Patient 14 the needle was directed too far cephalad entering the base of the aorta Mild signs of acute pericardial tamponade occurred followed by signs and symptoms of chronic tamponade during the next six weeks Eight pericardiocenteses were done beginning on the second post test day No hematologic abnormalities were found except a positive tourniquet test (Rumpel Leede) and slight bleeding of gingivae but the hemopericardium regressed coincidentally with vitamin C—vitamin P treatment (CVP capsules twice daily) Patient 45 required ¼ grain morphine subcutaneously for

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*[illegible] catheter No 417T Becton Dickinson and Company Rutherford N J or [illegible] Irvington Varnish and Insulator Co Irvington N J

TABLE II COMPARISON OF DIAGNOSIS OF VALVE LESIONS BY VARIOUS MEANS

TEST NO	PT	AGE	RHYTHM	RATE	PRESSURES, MM HG				PRESSURE EFFECTS			CLINICAL DIAGNOSIS			SURGICAL DIAGNOSIS			AUTOPSY DIAGNOSIS		
					L A	I V	AORTA	PERIPHERAL ARTERY	M S	M I	A S	M S	M I	A S	M S	M I	A S	M S	M I	A S
1	C B	30	A F	135	35	-	-	-	-	6½ mm	-									
									-	2+	-	2+	3+	0	-	-	-	-		-
2	P F	33	N	96	22	-	-	-	-	0	-	3+	2+	0	4+	0	0	4+	0	0
3	V P	44	A F	75	30	-	-	-	-	7½	-									
									-	2+	-	3+	1+	0	-	-	-	-	-	-
4	A E	46	A F	90	16	-	-	-	-	3	-									
									-	0	-	2+	1+	3+	-	-	-	-	-	-
5	J M	22	N	92	31	-	-	-	-	10	-				(myxoma)					
									-	4+	-	3+	1+	0	?	?	0	-	-	-
6	M C	38	A F	68	15	-	-	-	-	3½	-									
									-	1+	-	2+	3+	1+	-	-	-	-	-	-
7	V M	36	N	83	18	211/18	-	140/98	0	0	71									
								(cuff)	0	0	4+	2+	0	4+	0	0	4+	0	0	4+
8	A. H	50	A F	83	31	-	-	-	-	13½	-									
									-	4+	-	2+	2+	2+	-	-	-	-	-	-
9	D R.	36	N	85	31	-	-	-	-	3	-									
									-	0	-	3+	1+	0	4+	0	0	-	-	-
10	J S	31	N	85	28	100/3	-	-	25	0	-									
									4+	0	-	3+	1+	0	4+	0	0	4+	0	0
11	S P	15	A F	100	33	-	-	-	-	21	-									
									-	4+	-	-	4+	-	-	-	-	0	4+	0
12	A G	57	A F	90	29	-	-	-	-	0	-									
									-	0	-	3+	2+	0	-	-	-	-	-	-
13	H O	57	N	70	23	-	-	-	-	0	-									
									-	0	-	3+	1+	0	-	-	-	-	-	-
14	P D	27	N	120	-	-	122/88	-	-	-	-	0+	2+	0	-	-	-	-	-	-
15	M B	46	A F	115	25	-	-	-	-	0	-									
									-	0	-	2+	3+	3+	-	-	-	4+	0	1+
16	F E	57	A F	75	13	121/6	95/58	-	7	0	26									
									2+	0	2+	3+	0	1+	-	-	-	-	-	-
17	V W	39	N	80	26	103/9 13	-	-	17	0	-									
									4+	0	-	3+	2+	0	4+	0	0	-	-	-
18	M T	48	A F	90	24	96/14	-	-	10	4	-									
									3+	1+	-	2+	0	0	-	-	-	-	-	-
19	E C	27	A F	95	26	106/9	-	107/76	17	0	0									
									4+	0	0	3+	2+	0	4+	0	0	-	-	-
20	I S	35	N	60	17	121/5 11	-	-	12	0	-									
									3+	0	-	3+	1+	[illegible]	-	-	-	-	-	-

21	H M	41	N	[illegible]	[illegible]	100/15		90/60	10 3+	1 1	91 1+	2+	0	1+	2+	1+	1+	-	-	-
22	M P	24	AF	65	20	125/11	-	127/85	19 1+	0 0	0 0	2+	2+	2+	1+	0	0	-	-	-
23	M B	23	AF	80	14	100/9 13	-	93/70	5 1+	0 0	7 0	1+	3+	2+	-	-	-	-	-	-
24	M Z	40	N	90	15	152/14		118/50	1 0	0 0	31 1+	2+	0	1+	-	-	-	-	-	-
25	D B	51	AF	60	25	-	-	117/87	- -	1½ 1+	- -	2+	1+	2+	-	-	-	-	-	-
26	A I	55	AF	95	14	-	-	-	- -	0 0	- -	1+	2+	0	-	-	-	-	-	-
27	A I	55	AF	85	8	105/20	-	-	6 1+	0 0	- -	1+	2+	0	-	-	-	-	-	-
28	D B	51	AF	50	20	-	-	-	- -	6 2+	- -	2+	1+	2+	-	-	-	-	-	-
29	T A	15	N	110	22	110/6	110/90	-	10 1+	9 3+	0 0	2+	1+	0	-	-	-	-	-	-
30	C H	49	N	95	28	95/6 10	-	-	22 1+	15 1+	- -	2+	1+	0	-	-	-	-	-	-
31	O S	41	AF	70	23	100/6 7	-	-	17 1+	5 1+	- -	2+	1+	0	-	-	-	-	-	-
32	A S	30	AF	90	21	100/4 7	-	-	17 1+	0 0	- -	1+	2+	0	1+	1+	0	-	-	-
33	I I	20	AF	70	22	110/8 10	98/73	-	11 3+	3½ 1+	11 3+	3+	2+	0	-	-	-	-	-	-
34	S H	12	N	70	21	115/10	-	111/50	11 3+	0 0	1 0	1+	1+	1+	1+	0	0	-	-	-
35	F K	15	N	80	26	107/5	107/70	-	21 1+	0 0	0 0	1+	1+	0	1+	2+	0	-	-	-
36	R I	40	AF	75	28	105/9	-	-	18 1+	3½ 1+	- -	1+	2+	0	-	-	-	-	-	-
37	I H	36	N	90	10	151/7	-	-	33 1+	1 1+	- -	2+	1+	1+	-	-	-	-	-	-
38	F Y	32	N	90	25	117/0	-	-	25 1+	0 0	- -	3+	2+	0	1+	0	0	-	-	-
39	R K	40	AF	65	20	95/12 15	-	-	8 2+	13½ 1+	- -	1+	1+	2+	-	-	-	-	-	-
40	M C	28	N	80	31	100/5 8	-	110/67	29 1+	7½ 2+	11 1+	2+	2+	2+	1+	1+	1+	-	-	-

Pressure effects are expressed both in mm *Hg* and as 0 to 4+ grades of severity, as in Table I

L A = left atrium
L V left ventricle
A F atrial fibrillation
N normal sinus rhythm
M S *mitral stenosis*
M I mitral insufficiency and incompetence
A S aortic stenosis
No cases of aortic insufficiency were studied

TABLE II—CONT'D

TEST NO	PT	AGE	RHYTHM	RATE	PRESSURES, MM HG				PRESSURE EFFECTS			CLINICAL DIAGNOSIS			SURGICAL DIAGNOSIS			AUTOPSY DIAGNOSIS		
					L A	L V	AORTA	PERIPHERAL ARTERY	M S	M I	A S	M S	M I	A S	M S	M I	A S	M S	M I	A S
41	J M	49	A F	60	30	100/4 8	-	-	26 4+	0 0	- -	3+	0	0	4+	0	0	4+	0	0
42	I F	52	N	72	11	114/10 11	-	114/90	1 0	3 0	0 0	(Constr pericarditis)			-	-	-	-	-	-
43	E B	19	N	85	8½	120/3 7	120/75	-	5½ 1+	0 0	0 0	1+	3+	0	-	-	-	-	-	-
44	E R	34	A F	80	30	-	-	-	- -	9 3+	- -	1+	3+	0	2+	3+	0	-	-	-
45	C H	41	A F	100	26	100/2 6	-	-	24 4+	6½ 2 +	- -	2+	3+	0	3+	2+	0	-	-	-
46	P S	43	N	90	26	99/7 9	-	98/68	19 4+	0 0	0 0	4+	1+	0	4+	0	0	-	-	-
47	O D	40	N	80	15	115/9	-	107/81	6 1+	0 0	8 0	3+	2+	1+	4+	0	1+	-	-	-
48	T V	16	N	120	18	-	-	-	- -	8 3+	- -	2+	3+	0	-	-	-	-	-	-
49	F G	52	N	75	20	100/8 10	-	-	12 3+	0 0	- -	4+	0	0	4+	1+	0	-	-	-
50	R C	36	N	60	13	108/2 5	-	110/64	11 2+	0 0	0 0	3+	0	0	-	-	-	-	-	-
51	D T	40	A F	90	13½	106/4 6	-	100/75	9½ 2+	0 0	6 0	2+	3+	0	3+	1+	0	-	-	-
52	C C	36	N	105	20	107/5 8	-	109/77	15 4+	4 1+	0 0	3+	2+	0	-	-	-	-	-	-
53	J W	37	N	70	26	110/2 7	-	98/58	24 4+	0 0	12 0	3+	0	2+	4+	0	0	4+	0	0
54	R. Z	40	A F	60	17	130/5 8	-	100/68	12 3+	3½ 1+	30 3+	2+	3+	1+	3+	1+	2+	-	-	-
55	E A	45	A F	60	25	96/4 8	-	106/72	21 4+	2 0	0 0	3+	0	1+	-	-	-	-	-	-
56	I B	33	N	70	6	111/2 6	111/71	113/75	4 1+	0 0	0 0	2+	0	0	-	-	-	-	-	-
57	J B	20	A F	95	39	130/0 3	-	-	39 4+	5 1+	- -	2+	3+	0	4+	1+	0	-	-	-
58	A S	32	A F	120	11	121/7 9	-	135/79	4 1+	0 0	0 0	3+	1+	0	-	-	-	-	-	-
59	E C	49	A F	65	18	95/2 5	-	-	16 1+	½ 1+	- -	1+	0	0	1+	0	0	4+	0	0
60	D J	27	A F	65	12	98/10 12	-	110/74	2 0	0 0	0 0	1+	3+	0	-	-	-	-	-	-
61	H D	31	N	70	15	90/4 8	-	95/80	11 3+	0 0	0 0	2+	2+	0	2+	3+	0	-	-	-

(For footnote see page 383.)

relief of severe pleuritic chest pain after the test, although no evidence of organic cause was found on repeated auscultation, fluoroscopy, and x-ray films.

No emboli were dislodged, although there was history of embolization previously during cardiotomy or postoperatively, in 6 patients. No pneumothorax occurred. There was no evidence of esophageal injury.

Samples of pericardial fluid were sought for study at subsequent thoracotomy in 16 patients, and in 8 of these the fluid contained hemoglobin 1 to 5 Gm. per cent.

The needle was unintentionally lodged in vascular structures other than the left atrium in 10 patients, as listed in Table III. No complications resulted therefrom except as previously noted. Right heart catheterization through the needle was performed three times as a result of such location in the right atrium or vena cava, as an additional procedure.

TABLE III. ADDITIONAL VASCULAR ORGANS ENCOUNTERED AT LEFT ATRIUM PUNCTURE

PATIENT NO.	STRUCTURES
1	Superior vena cava, also pericardial cavity (clear fluid)
7	Right pulmonary artery
14	Base of aorta, also pericardial cavity (clear fluid)
16	Base of aorta
17	Right atrium
20	Right atrium
24	Intercostal artery
42	Right atrium
54	Right atrium
56	Right atrium, also pericardial cavity (clear fluid)

DISCUSSION

Estimation of the severity of valvular lesions by standard clinical and laboratory tests may sometimes be grossly in error. Therefore, judgment of the reliability of the pressure tests must be based on comparisons with surgical diagnoses by means of intracardiac and extracardiac palpation and with autopsy findings. In this series of cases, the comparisons show good agreement. In all cases (except one) where an operation had been performed the diagnosis as to the relative severity of the multiple lesions and the decision as to the proper surgical approach were correctly influenced by the pressure interpretations.

There were several unimportant discrepancies in the grading of cases of minor mitral insufficiency, and in one patient (No. 61) a major lesion of mitral insufficiency was not detected. This error occurred with relatively low left atrial mean pressure. It seems likely that the specific pressure effects of mitral stenosis or insufficiency will be exaggerated when the left atrium is distended with higher pressure. A less tense atrium and pulmonary vascular bed would result in less pressure rise from a given regurgitant jet.

Although the test has been quite reliable in this series, much further experience is needed for proper evaluation of diagnostic standards. The in

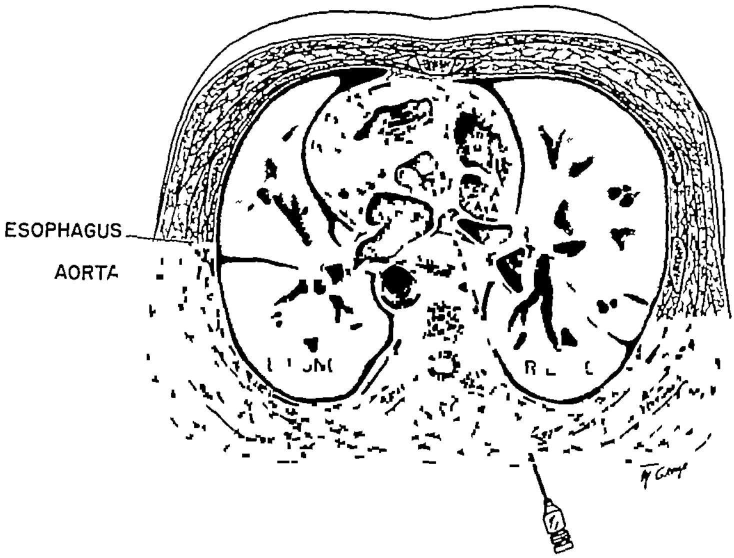


Fig 1*A* —Cross section view showing atrial puncture needle directed too high entering the base of the aorta

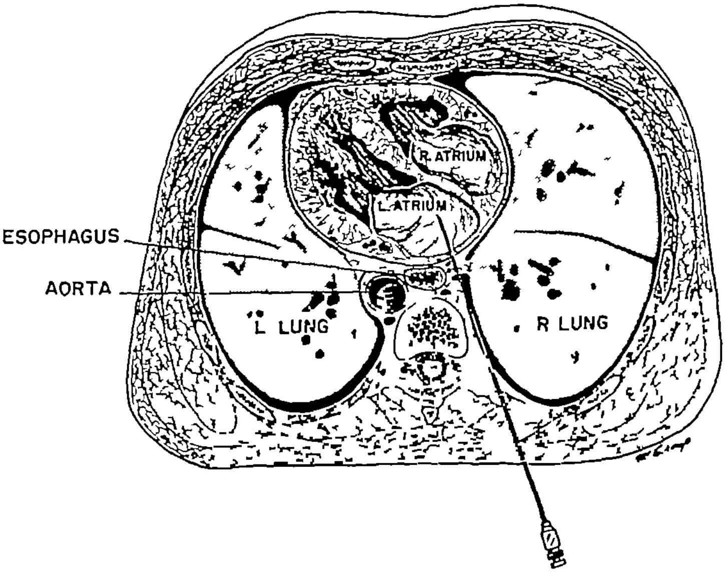


Fig 1B —Cross-section view showing the needle properly directed into the left atrium Further advance will encounter the right atrium (Fig 1*B* reprinted by permission of the Editor *Annals of Surgery*)

portant factors of heart rate and rhythm, pulmonary blood volume and vascular distensibility and cardiac output should be considered in measuring pressure effects

The procedure of transthoracic left atrium puncture can be varied in many other ways to suit individual requirements The technique of Bjork has been modified in this laboratory so as to use fluoroscopic guidance of the needle With standard fluoroscopic equipment this requires use of the prone position for insertion of the needle The pressure recordings of this study were made in such position If recordings in other reclining positions are desired the needle alone can be removed over the flexible catheter and then the body can be changed to the lateral or supine position A shift to the sitting position however, results in a compressing force at the epicardial or pericardial surface which can flatten a soft polyethylene catheter but not the stiffer Polyvinyl catheter Such maneuvers were carried out in 6 patients without complication

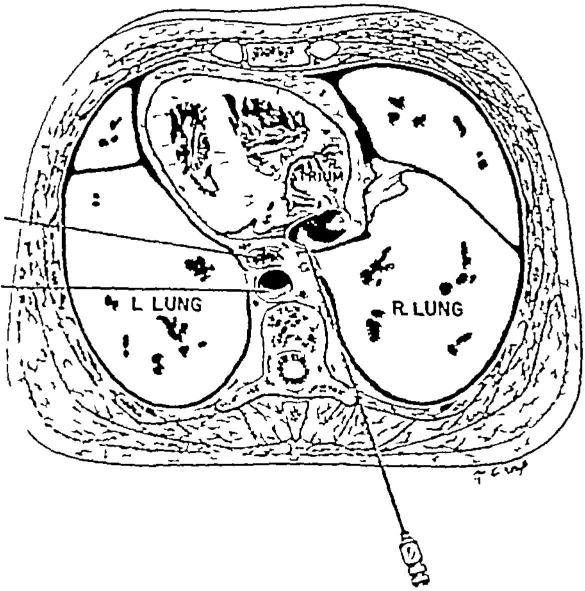


Fig 1c —Cross section view showing the needle directed too low entering the inferior vena cava or right atrium

The theoretical dangers of transthoracic left atrium puncture are many but no serious consequences have resulted in this series of cases Although the pericardial cavity commonly became contaminated with blood actual tamponade effects occurred in only 1 patient when the base of the aorta was entered directly from the pericardial cavity In another patient when the aorta was entered from the atrium no tamponade or other complication occurred

It appears that the likelihood of complications is small if the needle is directed accurately to the left atrium and especially if the aorta and pulmonary artery are avoided (Figs 1 and 2) The use of fluoroscopy as a guide seems to be helpful the left atrium being assumed to occupy the central area

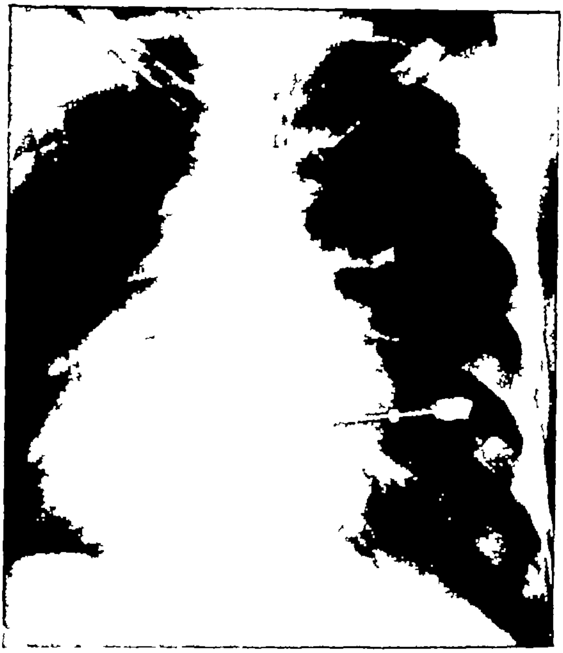


Fig 2A—Roentgenogram showing Patient J F (No 42) in prone position, as seen at fluoroscopy with needle placed in left atrium The marker indicates the point of skin entry on the right side.

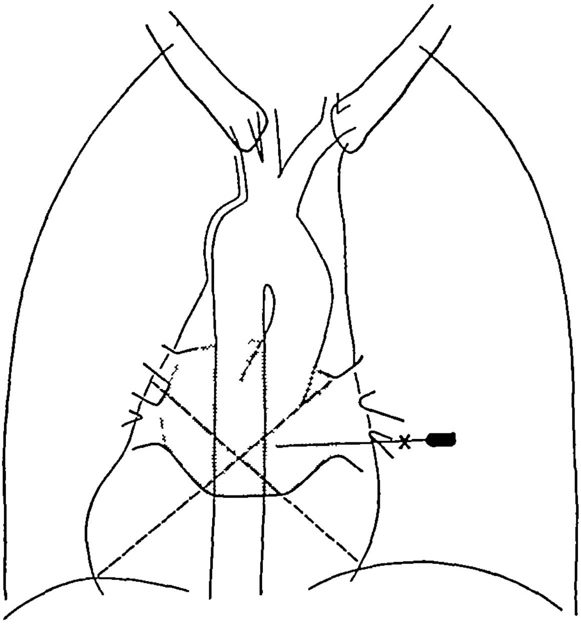
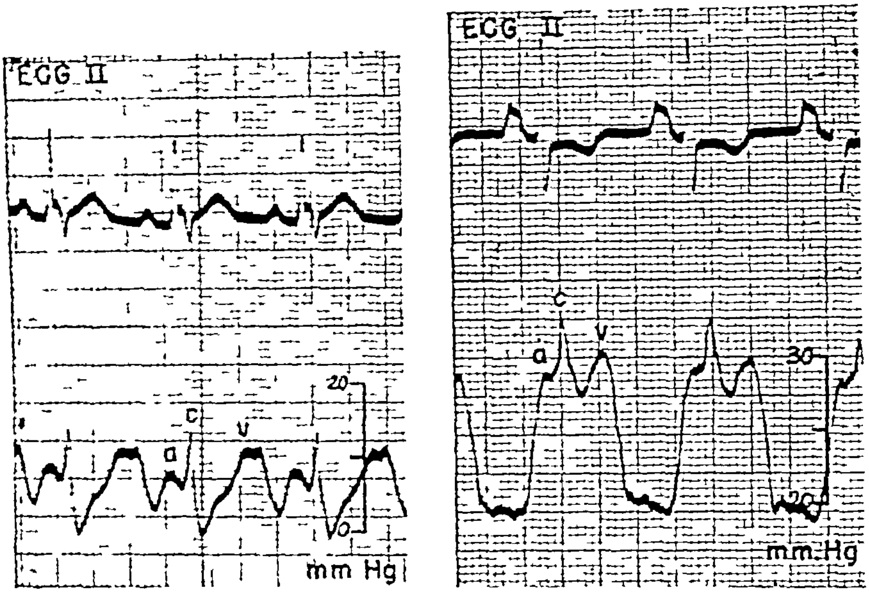


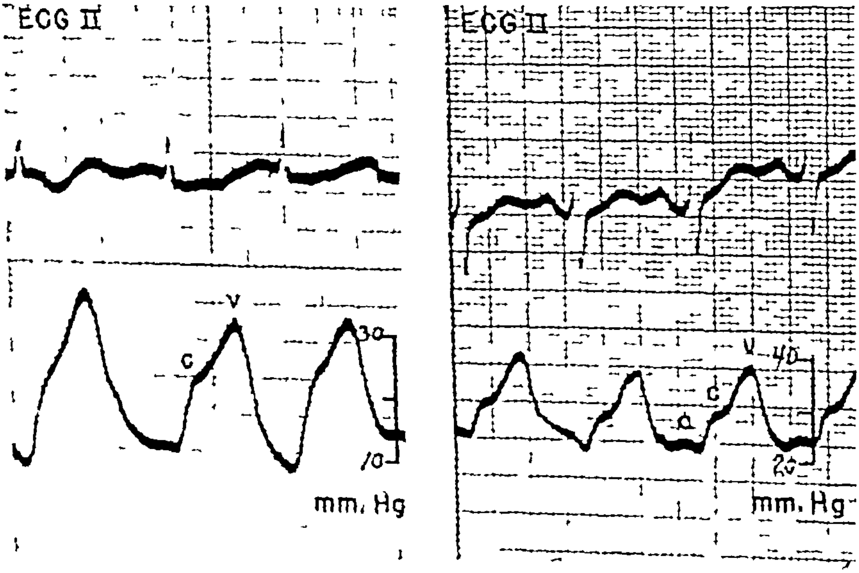
Fig 2B—Diagram indicating shaded area as the position of the left atrium on the heart shadow The needle is directed from the point of skin entry toward the intersection of imaginary lines at the center of the heart shadow



A *B*

Fig. 3.—*A*, Left atrial pressure recording in a heart with normal valves (obtained during right heart catheterization via a patent foramen ovale).

B.—Left atrial pressure recording in a heart with a tight mitral stenosis and no insufficiency.



C *D*

Fig. 4.—*C*, Left atrial pressure recording in a heart with mitral stenosis and a severe mitral insufficiency.

D, Left atrial pressure recording in a heart with pure mitral insufficiency.

([illegible] *D* is reproduced by permission of the Editor, *Annals of Surgery*.)

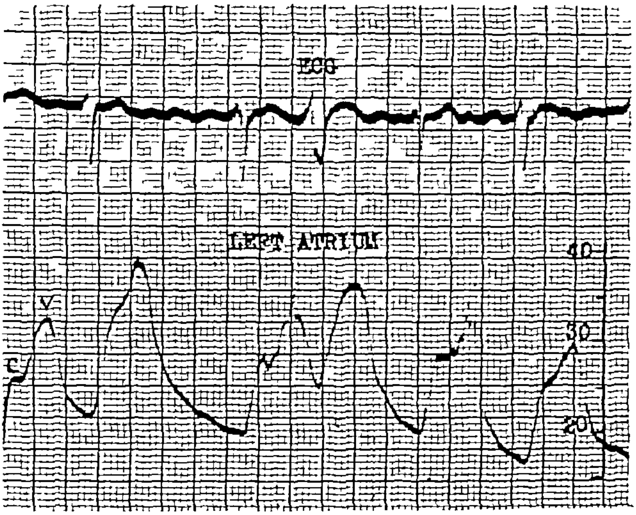


Fig 4A.—Left atrium pressure recording in Patient C.H. (No 45) mitral stenosis and insufficiency showing the immediate ascent of the V wave following the C wave due to the regurgitant pulse.

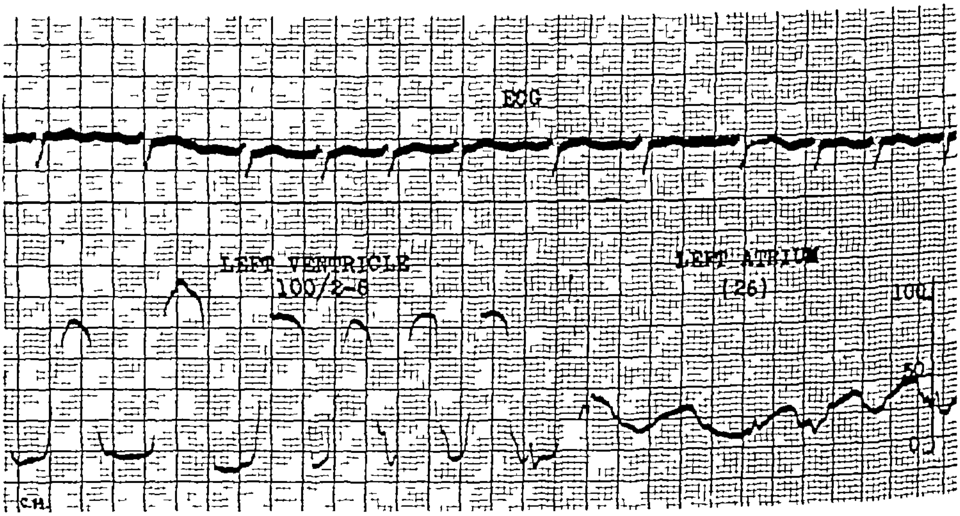


Fig 4B.—Patient C.H. (No 45) showing the recording during withdrawal of the catheter through the mitral valve. The pressure difference during diastolic periods is due to stenotic obstruction at the valve.

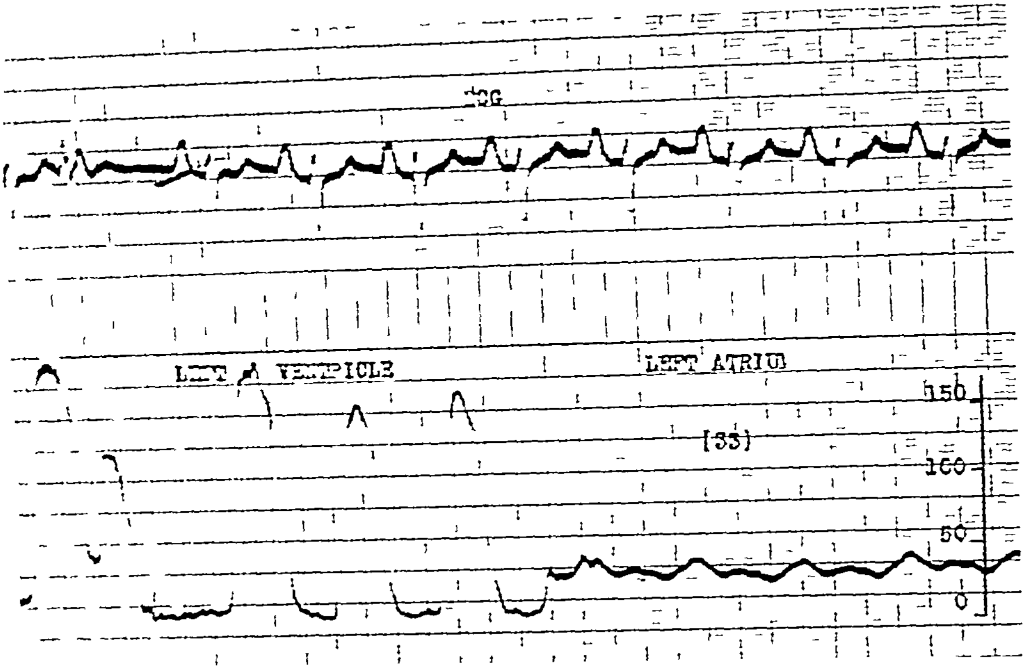
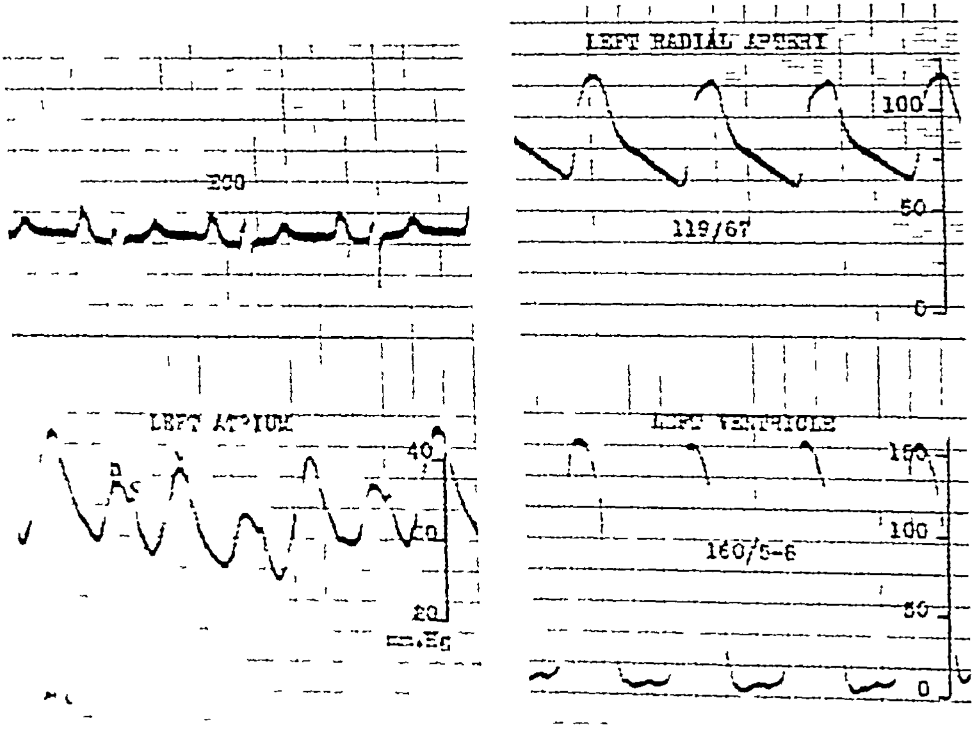


Fig. [illegible]1.—Patient M. C. (No. 40), mitral and aortic stenosis with slight mitral and aortic insufficiency. Recording of pressure during catheter withdrawal through the mitral valve showing diastolic phase pressure difference between atrium and ventricle due to mitral stenotic obstruction.



[illegible]

of the heart silhouette, and the needle being advanced toward an imaginary point in the exact center of the two-dimensional image With the point of entry into the skin as used here, and an angle toward the left of 25 degrees, both the bony cage and the lung were avoided with the needle No case of pneumothorax therefore occurred The transthoracic method of heart catheterization has so far been relatively safe

CONCLUSIONS

1 Sixty-one pressure recordings were obtained at transthoracic left atrium puncture for diagnosis in 58 patients

2 Left heart catheterization was performed through the left atrial puncture needle in 52 of these tests Diagnostic interpretations were compared with a series of observations at 26 later heart valve operations and 8 autopsies

3 Only one major disagreement occurred in these comparisons The pressure tests therefore appear to be reliable in the preoperative diagnosis of heart valve lesions

4 Further precision should nevertheless be sought in the future by measurement of cardiac output, which is a major factor influencing the quantitation of the various pressure abnormalities

5 No fatalities nor lasting sequelae resulted from the tests There were only 3 minor complications, occurring in 3 of the first 14 patients of the series

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DISCUSSION

DR WILLIAM S BLAKEMORE, Philadelphia, Pa—I want to congratulate Dr Fisher on the work which he has pioneered in this country, and this paper in which he has pointed out the diagnostic possibilities of this test While working in Professor Crafoord's clinic with Dr Bjork and Dr Malmstrom, we were able to develop an original method of catheterization of the left side of the heart Later, Dr Schnabel and I further modified the procedure and we now use three small catheters

The first catheter is inserted through a No 18 thin walled needle into the left auricle and through the mitral valves into the left ventricle A second catheter is inserted into the auricle and a third is inserted via a percutaneous needle puncture into the femoral artery and passed to the aortic arch near the valve We have used this procedure in 14 patients who were poor operative risks and in whom other routine studies for evaluation of their cardiac disease had not proved the diagnosis There is some risk to this procedure and Dr Björk had one death in the series he studied, and we have had one death in this series

In a patient with pure aortic stenosis a ventricular pressure was recorded of 160 mm Hg and an aortic pressure of 70 mm Hg The diagnosis of aortic stenosis was confirmed at operation Interestingly enough, when the cardiac rate changes in these patients the pressure gradient across the valve decreases if the cardiac output remains the same In a patient with pure mitral stenosis, it has been noted that the pressure gradient is maintained throughout ventricular diastole

The first sound is markedly accentuated in mitral stenosis, and Dr Schnabel has attributed this to the closure of the valves during the steep rise of the ventricular pressure The aortic curve does not coincide exactly with the ventricular curve in the time axis because the tip of the catheter was located in the arch rather than at the aortic valves

In another patient with mitral regurgitation and no mitral stenosis, there was a rise in the left auricular pressure during ventricular systole, and an insignificant pressure gradient across the mitral valve during ventricular diastole

A delayed rise in the aortic pressure with the catheter placed at the level of the aortic valve may be due in some degree to aortic stenosis Withdrawal curves with one catheter recording the pressure in the left ventricle, and another in the left auricle, show that as the left ventricular catheter is withdrawn into the auricle the two pressure curves can be superimposed, confirming the accuracy of this type of recording It would therefore seem that this is a very reliable diagnostic method for determining mitral and/or aortic stenosis We have, because of the risk involved, used this procedure only when other methods of cardiac evaluation have not provided a precise diagnosis in patients who are poor operative risks

DR CLARENCE CRAFOORD, Stockholm, Sweden—I am sorry I did not have a program of this meeting before I left Stockholm as I wanted to see if there was something I wished to discuss, and as a result I have no slides Dr Fisher's paper and Dr Blakemore's discussion are interesting to me, as this method of recording was first carried out in my service We had a few cases where the clinical symptoms led us completely astray in deciding whether insufficiency or stenosis was predominant, and for that reason this method was developed I want to correct one thing Dr Fisher said, he said that we did not use fluoroscopy to judge how the needle was introduced, but we always control this with fluoroscopy and, if necessary, x ray photographs to see if the needle is in the correct position

I think we have had approximately another 100 cases which have been explored, the total number is about 200 We had one death That patient never should have been subjected to this procedure We were unable to identify a rather large shadow posteriorly, which had been interpreted as a large auricle, but it proved to be an aneurysm at the [illegible] of the aorta which was passed by the needle The patient went into shock because of intrapericardial bleeding A successful attempt was made to suture, but the patient did not recover We had 1 case of rather severe intrapleural bleeding in this series which necessitated multiple aspiration and streptodornase streptokinase treatment We do not know the exact cause of this bleeding but the patient recovered from this complication and was operated on for mitral stenosis about two months afterward with complete success and without complications

Otherwise there have been some minor complications such as small pneumothoraces [illegible] small bleeding in the pleural space, which have not necessitated any treatment There was recently, however, one case of rather massive intrapericardial bleeding which [illegible] a couple of aspirations of the pericardium When we started the investigation [illegible] thin [illegible] was passed through the needle Attempts to use heavier needles in order to pass thicker catheters have been abandoned because of the greater risk of after [illegible] It is always easy to pass the catheter into the auricle and through the mitral valve into the left ventricle We have [illegible] in more than 40 per cent of the cases [illegible] the aorta We have also used two catheters in order to ob[illegible] [illegible] in the ventricle and auricle, or either of them and the [illegible] to take the catheters out [illegible] were stuck This [illegible] of the catheters had been discussed The curves showed that it was a definite mitral stenosis We had to take the patient to the operating room, and at operation, when successful commissurotomy was performed, we found that the two catheters had made a knot of which any seaman would be proud.

DR A HIMMELSTEIN, New York, N Y—I should like to continue this discussion basing it on our experience with 8 transbronchial needlings of the left auricle Our experience has been with mitral disease, and I should like to show some slides to validate the recordings in the operating room as compared to recordings with intact chest wall.

This slide is a tracing made in the operating room by an apparatus which enables us to use identical sensitivity manometer recording systems and to superimpose them so that we get a tracing which is very similar to the one in Wiggers' textbook, which Dr Fisher showed In this patient with mitral stenosis, needles were placed in the left auricle, left ventricle, and aorta We see here the ventricular tracing, the aortic tracing, and the auricular tracing, and the hallmark of any stenosis is very obvious here in the gradient of pressure between auricle and ventricle during diastole This is a patient who had been operated on once before for mitral stenosis I would interject here that this is not a recurrence, since when we spoke to the surgeon who did the first procedure we realized that this valve had not been opened

This slide shows a transbronchial puncture in the same patient, done preceding operative intervention It shows a slightly damped ventricle tracing The needle is an 18 gauge thin walled one, 50 cm long, that goes through the bronchoscope, and a catheter is passed through this into the ventricle The catheter is similar to the one Dr Fisher uses The auricular tracings are taken through the needle and are recorded with a much better frequency response We have a pressure in the auricle which is elevated, and it brings out the marked pressure gradient during diastole and the fact that these tracings are very similar both in contour and absolute value to what we get in the operating room

This slide shows the postoperative tracing in this patient done in the operating room One should be able to tell when a good opening of the mitral valve has been secured. You get rid of the gradient which here (during all of diastole) has been reduced to almost zero, and at the end of diastole, to zero

We too have had the problem of the diagnosing of mitral insufficiency, and in this context I show the next case

(slide) These are the transbronchial tracings, the auricular tracings, and the ventricular tracings, to show that this patient had almost no diastolic gradient and therefore no significant mitral stenosis by our criteria However, on the insistence of our medical colleagues, and some suspicion of our own—this is the first needling of the auricle we did—we proceeded to operate on this patient

(slide) Here is the tracing made in the operating room, showing that the gradient of mitral stenosis is minimal, and when a finger was inserted into this patient's auricle, the problem was largely one of insufficiency with no stenosis

I think it is extremely difficult to diagnose mitral insufficiency even by tracings, and we have seen rather significant mitral insufficiency which was not evident on tracings from the auricle

DR CHARLES P BAILEY, Philadelphia, Pa—We, too, have been stimulated by the report from Dr Crafoord's clinic by Dr Bjork and his associates, and with the direct help of Dr Donald Fisher we were able to start upon a similar program some months ago We would like to take exception to Dr Himmelstein's saying that tracings taken in the operating room are entirely reliable because, at least with our equipment and technique, there has been a great difference between them and the preoperative tracings obtained by this method We have come almost to discard measuring the pressure in the operating room for that reason Undoubtedly the discrepancy is related to a diminished stroke output during the course of anesthesia and surgery

In valvular disease, one frequently is hard put to decide what lesions are present what lesions are important, which to attack first, and which may safely be left alone This method of investigation has been of great value to us, although we have carried it out in only 29 patients. There was one death in this series occurring a day after left heart catheterization. This was a patient with severe insufficiency of the mitral valve. At postmortem the death did not seem in any way to be related to the procedure. We have had several patients with fluid in the pericardium which was sanguineous. We are pretty sure that we know all about this complication because we have limited this study to patients who were about to be operated on the next day or the day after.

There was one instance of inadvertent puncture of the aorta, due to misdirection of the needle. Some degree of hematoma of the mediastinum and periaortic region resulted but it was in no way serious.

Recently Dr Goldberg our physiologist has been doing simultaneous right heart catheterization and left heart catheterization thus being able to measure not only the cardiac output but the pressures on the left side, and also the condition of the tricuspid valve, pulmonary capillary resistance of the lung, and things of that sort. We feel that the procedure is quite safe and reasonable and that it should be employed more often, especially when one is dealing with suspected multivalvular disease. We feel that Dr Crafoord and his group and Dr Fisher, who took the lead in this country have certainly given us a very worthwhile tool for evaluation of these problems.

DR OSLER ABBOTT Emory University.—I admit there is a difference between tracings taken in the laboratory and in the operating room but these are differences only of degree and both tracings can be usefully correlated. We have been studying the pressures in the pulmonary artery, pulmonary vein and auricles at the time the chest is open. These have been compared to preoperative cardiac catheter studies. The tracings obtained at the time of open chest are variable according to three basic factors: first, the intrabronchial pressure produced by the ventilatory pressure of the anesthesia machine, two the drugs acting at the time the pressure is taken and three the patient's position. Pressures at cardiac catheterization and at the operating table will parallel each other in their contour. An interesting finding in this study of left heart pressures at the table, with controlled endobronchial ventilatory pressures ranging from zero to 5 mm Hg is that the pulmonary venous pressures are negative only during the zero or expiratory phase, and then they may have a negative characteristic of no more than 1 to 3 mm Hg. When the endobronchial ventilatory pressures are increased to (1) zero at 10 mm Hg and then to (2) zero to 20 mm Hg the pressure readings in the pulmonary vessels normally parallel the endobronchial ventilatory pressures. This response varies somewhat in different pulmonary and cardiovascular disease states.

(Slide) It was interesting to us in looking over a respirator that had a negative phase of expiration to find that a negative pressure phase appears in the pulmonary artery. [illegible] that there may be a phase of backflow of blood in patients in the lateral position from the pulmonary arterial bed of the uppermost or exposed lung over to the contralateral lung. This is a significant degree of negative intra-arterial pressure. This [illegible] present in patients with significant degrees of pulmonary arteriosclerosis.

(Slide) In the pulmonary vein a marked degree of constant negative pressure exists at all times when a negative phase respirator is used. When the left auricle is studied [illegible] the transmural pressure exactly parallels the venous pressure. In the open [illegible] using a biphasic respirator and the [illegible] machine (with a negative expiration [illegible]) we have found constant recordings of negative pressures in the pulmonary [illegible] expiration and at all times in the pulmonary venous system and [illegible] are the findings in the essentially normal cardiovascular patient.

[illegible] controlled biphasic pressure respirator for [illegible] the remark that the ventilatory pressure and [illegible] had to do with the paralleling of intra[illegible] laboratory and in the operating room.

[illegible] Moscow [illegible] I'd like to show a slide which indicates [illegible] exactly parallel [illegible] criteria by [illegible]

We have had 30 cases in conjunction with Dr Thomas Burford at Barnes Hospital and I think a few points of difference between our technique and Dr Fisher's might be worth mentioning First, we do not use the Trendelenburg position, but in all instance have the patient lying on his right side We have not used the fluoroscope This has made the procedure rather simple and has allowed us to get more freedom of movement. The left auricle has been entered in all instances In 1 case, the left ventricle was entered first and in 2 cases the pulmonary artery first, but upon withdrawing the needle it could then be passed into the left auricle After the auricle is entered, a polyethylene catheter is inserted through the needle In passing the catheter through the auricle we have also had uniform success in passing it into the ventricle In 4 of these cases we were unable to pass the catheter into the ventricle These were in our first seven attempts Since then we have had no difficulty

With regard to passing the catheter into the aorta, we did not attempt to do this, as we felt that it added little to the clinical impression we obtained We have had no serious complications and no incidence of bleeding or hemothorax. Interestingly enough, there was a small amount of serosanguineous fluid at operation within the next 24 to [illegible] hours This has been a very tiny amount of fluid, and no noticeable puncture could be seen in the left auricle

I think I might summarize by saying that it is our feeling that the procedure as described by Dr Fisher is a simple one and very useful clinically, and that complicating it by adding additional factors would make it more complicated and bulky We feel it can be done without such additional things

DR GEORGE W B STARKEY, Boston, Mass —I should like to ask the author or any of the discussants of his paper how well their pre and postoperative measurements of the gradient across the aortic valve, using the Bjork method, have correlated with measurements of the gradient at the time of surgery, both before and after dilating the aortic valve

I should like to congratulate Dr Fisher for this excellent paper

DR DON L FISHER, Pittsburgh, Pa (Closing) —The only answer I have to this last question is to cite 1 case, in which there was calcified aortic stenosis At a pre operative left heart catheterization test, the systolic pressure decreased by 70 mm Hg at the aortic valve At operation, the same pressure drop was determined by passing the catheter down the aorta from above, through the opening of the aortic incision, and then a systolic pressure drop of 40 was obtained at the valve I was not able to make post operative recordings, unfortunately I do not have other such comparative tests regarding aortic stenosis

We have, however, found in mitral stenosis a good qualitative correlation between preoperative measurements and tests at operation The test conditions appear to affect the measurements For example, in one case of mitral stenosis there was a diastolic pressure drop of 39 mm Hg at the mitral valve, preoperatively This patient was in sufficiently sedated, and was apprehensive At the time of operation, the pressure drop was 20 before finger fracture of the valve, and 9 afterward, with less than an ideal result on palpation of the valve

Cardiac output measurements, study of the heart rate, and so on, will be helpful in the use of pressure recordings Body position may have little effect on the contour of the left atrial pressure curves We studied this in preoperative tests by withdrawing the needle over the catheter, leaving only the soft catheter in place Change to various lateral, sitting, and supine positions then was found to cause no significant change in contour of the left atrial pressure curves Exercise in the supine position caused elevation of left atrial pressure with increase of any regurgitation effect

A LABORATORY AND CLINICAL EVALUATION OF OPERATIONS FOR CORONARY ARTERY DISEASE

DAVID S. LEIGHNINGER, M.D. (BY INVITATION)

CLEVELAND, OHIO

DURING the past twenty-three years Beck and his associates[1] have established the principles of improving the blood supply to the heart. These are (1) the even distribution of blood by intercoronary arterial communications, (2) elevation of the coronary sinus pressure, and (3) the addition of blood from outside sources by (a) extracoronary communications and (b) arterialization of the coronary sinus.[1]

In recent years the importance of intercoronary arterial communications as a mechanism of benefit has become more apparent. An appreciation of this importance depends upon an understanding of the mechanisms by which patients die from coronary artery disease. There are two types of death.[1] One type follows extensive degeneration of the myocardium. The myocardium gives way and heart failure develops. This type of death has been called *muscle death*. The other type of death follows a break in the coordinated mechanism of the heartbeat. The pumping action of the heart is destroyed and death occurs immediately. This type of death has been called *mechanism death*. The hearts of patients who die a mechanism death may show little or no degeneration of the myocardium. No recent lesion may be found in either the arteries or muscle.[2,3] Presumably these hearts were capable of continued function had not a break in mechanism occurred. Analysis of 950 deaths from coronary artery disease reported by Yater and co-workers[3] shows that about 90 per cent died from a break in mechanism and about 10 per cent died from heart failure.[1] Attention is directed to this large group of patients who develop a break in the coordinated mechanism because something can be done to prevent this break.

The hearts in many of these victims are capable of continued function provided the break does not occur, whereas in the other group of patients nothing can be done to restore myocardium after it degenerates into scar.

The hearts in which the coordinated mechanism is lost are electrically unstable. Experimentally a heart can be made unstable and the normal mechanism can be readily lost.[4] Fig. 1 is an electrocardiographic tracing which was taken from the surface of the left ventricle of a normal dog heart. The electrode

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[illegible] University [illegible] of Medicine and the University Hospitals [illegible] grant from the [illegible] Public Health Service and [illegible] Laboratory of Cleveland [illegible] Drs. [illegible] Mexico City [illegible]

[illegible] Thirty-fifth Annual Meeting, The American Association for Thoracic Sur[illegible] was placed directly on the epicardium These tracings showed uniform electrical potential during diastole and during the repolarization phase of systole The "S-T segment" of the complex is recorded during the repolarization phase If a portion of the ventricle is made anoxic by ligation of its arterial blood supply, then the electrocardiogram is altered over this part of the heart

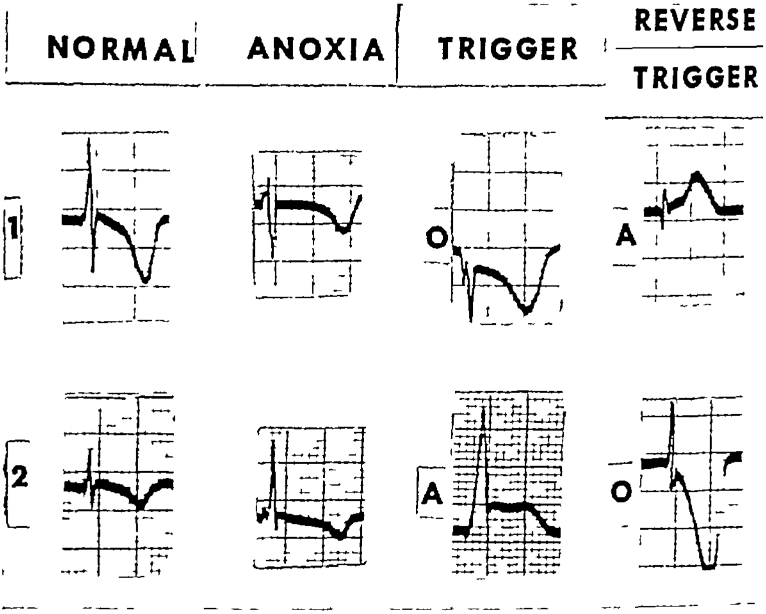

Fig 1 —Epicardial electrocardiographic tracings from a dog heart. The complexes in line 1 were taken from the same location in the descending area The complexes in line 2 were taken from the same location in the circumflex area O = oxygenated area A = anoxic area

The S-T segment is elevated over the entire anoxic area and the S T segment is depressed over the adjacent oxygenated area (Fig 1) This indicates that during diastole the anoxic area is electrically negative as compared with the oxygenated myocardium The area rendered anoxic by arterial ligation is sharply demarcated from the pink oxygenated area This is readily visible The transition between blue and pink muscle is an extremely narrow zone Measurements from one zone to the other were 10 to 20 millivolts This indicates electrical imbalance between the blue and pink areas of the heart and produces what might be referred to as an electrically unstable heart because it might fibrillate It is interesting to note that a uniformly anoxic heart such as is produced by clamping the intratracheal tube for periods of six to eight minutes is a relatively stable heart In this type of experiment the heart becomes extremely blue and it does not fibrillate Approximately 50 such experiments were performed by me and none of these hearts fibrillated At the suggestion of Dr Beck a reverse trigger was made by injection of red blood into the descending ramus or the circumflex ramus of the left coronary artery This produces a pink trigger in a blue heart and the epicardial leads were negative over the blue areas compared to the pink area. The same difference in electrical potential was produced except that the alterations were reversed. Such hearts became unstable and some of them went into ventricular fibrillation. These experiments demonstrate that blue muscle in contact with pink or pink muscle in contact with blue produces currents which can make the heart fibrillate. The dangerous area is in the plane of contact between the two areas. This danger can be reduced by diminishing the difference in oxygen tension between the two areas and this can be accomplished by establishing arterial communications between the two areas. The importance of intercoronary communications is obvious. This demonstration by experiment can be applied to the vast majority of people who die from coronary artery disease and it explains death occurring in hearts that show little or no disease.

The quantity of blood necessary to prevent a break in mechanism is not large. Eckstein and associates have shown that in every experiment 4 c c of additional blood per minute delivered to the circumflex area prevented death within one hour following circumflex artery ligation. In control dogs the mortality within one hour was 70 per cent following circumflex artery ligation.

Intercoronary arterial communications can distribute blood evenly to all parts of the myocardium and thus maintain electrical stability. Ninety-one per cent of normal human hearts have no intercoronary communications demonstrable by injection studies[6] In normal dogs 90 per cent have insufficient intercoronary communications to prevent death from circumflex artery ligation and 70 per cent have insufficient intercoronaries to prevent death from either descending or right coronary artery ligation.

Permanent intercoronary arterial communications can be produced by operation. Various stimuli or combinations of stimuli have been employed at operation and reported by Beck[2]

A quantitative evaluation of intercoronary arterial communications can be made by the Mautz-Gregg backflow method. The circumflex ramus of the left coronary artery is ligated near its origin and cannulated distal to the ligature (Fig. 2). The artery is perfused with arterial blood by way of a cannula in the carotid artery. This supplies oxygenated blood to the circumflex area of the myocardium except when a backflow measurement is made. To measure the backflow the perfusion is stopped and a side arm of the cannula is opened. Blood from other coronary arteries flows across whatever intercoronary communications may be present into branches of the circumflex artery. From these branches it flows in a retrograde direction out of the artery through the cannula and the side arm. It is collected for a period of [illegible] and measured. The backflow is expressed as cubic centimeters per minute. Several measurements are made and the results averaged. [illegible] with the mean aortic blood pressure [illegible] The greater the number and functional capacity of the intercoronaries, the greater will be the backflow After backflow measurements have been made the circumflex perfusion is stopped The only blood that reaches the circumflex area of myocardium is that which flows across intercoronary communications Electrocardiographic tracings, using lead aV_R, are taken for a period of nine or ten minutes after the perfusion is stopped Electrocardiographic changes are graded according to the criteria of Eckstein and Leighninger[8] Changes of "two plus" or less are arbitrarily considered as showing evidence of protection Electrocardiographic evidence of protection correlates well with the one-hour mortality of 70 per cent from circumflex artery ligation as found by Eckstein,[5] but shows greater protection than was found in the long-term mortality of 90 per cent from circumflex artery ligation as reported by Leighninger and Dalem[9]

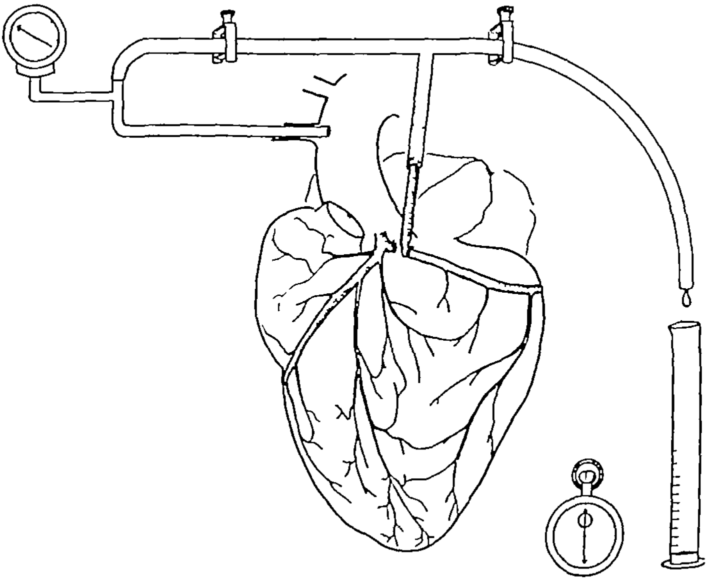

Fig 2—Mautz-Gregg backflow method Circumflex artery ligated and distal segment cannulated Cannula perfused by way of the carotid artery Blood pressure recorded from the carotid cannula Side arm from circumflex cannula is clamped during perfusion. When carotid cannula is clamped and side arm opened backflow blood flows against atmospheric pressure. The end of the side arm tube is at the level of the heart. Backflow blood is collected for a period of 30 seconds and expressed as backflow in cubic centimeters per minute

Backflow determinations have been made on a group of 67 normal control dogs* The average backflow was 3 8 c c per minute The range was from 0 4 c c per minute to 21 0 c c per minute The median backflow was 3 0 c c per minute Twenty-five per cent of the normal dogs showed electrocardiographic evidence of protection

Backflows from normal dogs were compared with backflows obtained from 41 Beck No 1 operated dogs Operation consisted of abrasion of the epicardium and pericardium, partial coronary sinus ligation, application of

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*Eckstein[10] studied 41 of these normal dogs

0 2 Gm powdered asbestos and grafting of the abraded pericardium to the surface of the heart Backflow determinations were made from three weeks to one year after operation The average backflow was 8 5 c c per minute The range was from 0 6 c c per minute to 26 0 c c per minute The median was 7 0 c c per minute Sixty five per cent of the dogs showed electrocardiographic evidence of protection The backflows for the Beck No 1 operated dogs are significantly different from those of the control dogs The probability of such a difference occurring by chance alone is greater than one chance in 1 000 Five chances out of 100 is usually considered statistically significant

The Beck No 1 operation added an average of 4 7 c c per minute of blood to the circumflex area by way of intercoronary communications Operation stimulated the growth of these communications Since they persisted for at least one year after operation they are considered permanent

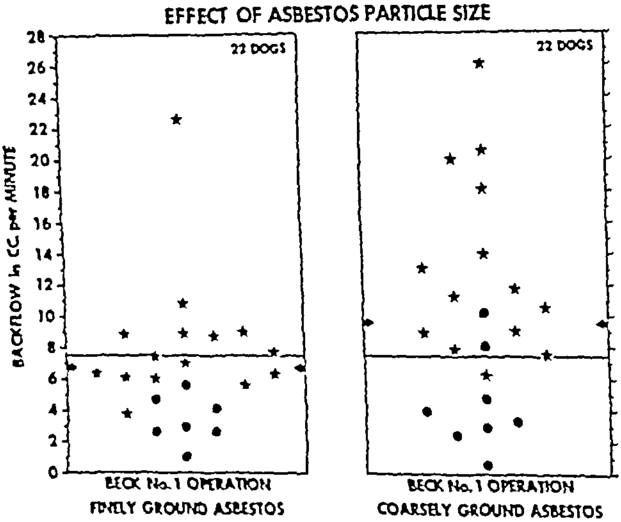

Fig 2 —Effect of asbestos particle size on the No 1 operation Each dot or star represents the backflow from one dog A star indicates presence of electrocardiographic evidence of protection The horizontal line is through the median for the entire group of dogs The average backflow for each group is indicated by arrows

The 4 7 c c per minute of blood added by operation is a significant quantity of blood It prevents electrical instability in hearts following coronary artery ligation It was responsible for lowering mortality to 26 6 per cent following descending artery ligation in dogs protected by the No 1 operation Mortality from descending artery ligation was 70 per cent in normal dogs[1] This quantity of blood was responsible for preserving the viability of myocardium following artery ligation as shown by the reduction by 70 per cent of infarct size in protected dogs as compared with normal dogs[11]

The effect of coronary sinus ligation on the Beck No 1 operation was studied In all dogs the pericardium and epicardium were abraded and 0 2 Gm powdered asbestos applied to the surface of the heart In 5 dogs the sinus was not ligated and backflows averaged 8 1 c c per minute In 5 dogs the sinus was completely ligated near its ostium The average backflow was 5 5 c c per minute In 41 dogs the sinus was partially ligated The average backflow was 8 5 c c per minute The rationale for including partial sinus ligation as a step in the No 1 operation includes the results of acute studies by Eckstein and associates[12] Elevation of the coronary sinus pressure followed immediately by circumflex artery ligation lowered the one-hour mortality from this artery ligation from 70 per cent in control dogs to 35 per cent in the dogs with sinus pressure elevation The immediate benefit thus demonstrated probably accounts for at least some of the early postoperative benefit noted by some patients following operation

Fig 3 compares the effect of asbestos particle size on the Beck No 1 operation in a group of 44 dogs The asbestos used in one group was finely ground in a mortar and sifted through several layers of gauze In these dogs the average backflow was 6 7 c c per minute The asbestos used in the other group of dogs was either lightly ground in an ordinary household food grinder or used just as it was received from the manufacturer The average backflow for these dogs was 9 1 c c per minute The coarser-ground asbestos is now standard for use in patients

Pilot studies were carried out in a group of 161 dogs following a variety of operative procedures

Forty-three dogs were studied to determine the effects of the individual components and combinations of components of the Beck No 1 operation The average backflow following complete sinus ligation was 11 0 c c per minute McAllister and Leighninger[13] reported a 4 2 per cent mortality following complete sinus ligation in dogs One of Dr Beck's patients had complete sinus ligation alone This patient received an excellent result It has been shown previously, however, that, in combination with abrasion and application of asbestos, partial sinus ligation gave better results than complete sinus ligation Postoperative morbidity in dogs following complete sinus ligation was slightly higher than following partial sinus ligation, either alone or in the complete Beck No 1 operation In 7 dogs the sinus was ligated to either 2 or 3 mm The average backflow was 7 0 c c per minute In 7 dogs the epicardium was abraded and backflows averaged 6 9 c c per minute In 5 dogs 0 2 Gm powdered asbestos was applied to the surface of the heart The average backflow was 5 7 c c per minute In 5 dogs the heart was abraded and asbestos applied The average backflow was 8 1 c c per minute In 5 dogs the heart was abraded and the sinus ligated to 3 mm Backflow averaged 10 8 c c per minute In 5 dogs the sinus was ligated to 3 mm and asbestos applied The average backflow was 8 5 c c per minute The average backflow for the 43 dogs studied was 8 5 c c per minute Sixty-eight per cent of the dogs showed electrocardiographic evidence of protection These studies show that each of the components of the No 1 operation, either singly or in combination, stimulates the growth of intercoronary communications The differences found in this small series are not statistically significant. The effect of the components when combined in the complete operation, however, is not necessarily the sum of the benefit from each.

Asbestos is a naturally occurring mineral composed mainly of silica and magnesium oxide, small amounts of aluminum and ferric oxide, and traces of other compounds. Its physical properties and chemical composition vary slightly depending upon where it is mined. Talc is similar in composition but contains larger quantities of silica. It also varies in composition depending upon where it is mined. Pilot studies were made in a group of 49 dogs using each of ten varieties of asbestos or talc. Each differed slightly in chemical composition and physical properties. The backflows obtained together with the averages for each group of dogs are shown in Fig. 4. In each dog the heart was abraded, the sinus partially ligated, and the test substance applied to the surface of the heart. The average backflows varied from 3.3 cc. per minute to 9.9 cc. per minute. No one irritant was significantly better than another considering the small number of dogs in each group. Also tested with this group was a ground plastic, the application of one layer of surgical gauze sponge to the surface of the heart, and the application of isolated pectoral muscle strips to the surface of the heart. The rationale for the use of muscle strips is as follows: Coronary artery ligation [illegible] normal stimulus to the growth of intercoronary communications. This [illegible] to be due to high pressure differences between the occluded artery [illegible] and probably to anoxia. In infarction there is [illegible]. The products of degeneration are absorbed through the lymphatics [illegible]. Perhaps some substance was present in the products

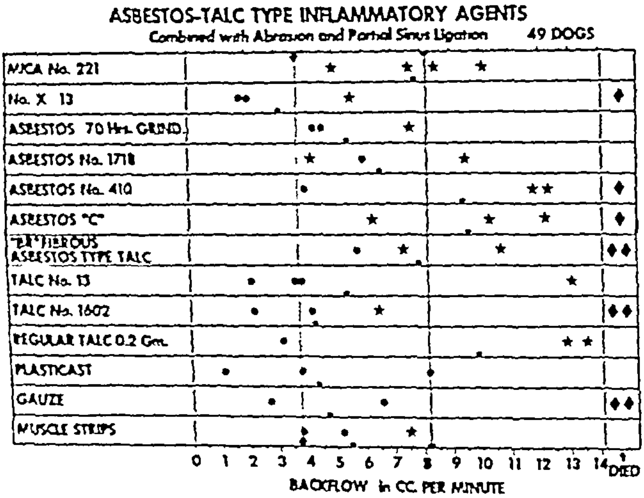

Fig. 4.—The effect of various irritants on the No. 1 operation. Each dot or star represents the backflow from one dog. A star indicates presence of electrocardiographic evidence of infarction. Each diamond represents a postoperative death. The dotted vertical line indicates the average backflow for control dogs. The solid vertical line indicates the average backflow for the No. 1 operation [illegible]. The average backflow for each group of dogs is indicated by an arrow. The names in the left column are code names for various types of irritant.

of degeneration which stimulated the growth of intercoronary communications Products of degeneration of the muscle strips applied to the surface of the heart would be absorbed at least in part by the lymphatics of the myocardium and any stimulus present could exert its influence The average backflow of 5 5 c c per minute obtained in this group of dogs indicates that if such stimuli were present their influence was not great There were 9 postoperative deaths in the 49 dogs tested, a mortality of 18 per cent The average back flow for the entire group of 40 dogs was 6 5 c c per minute Fifty per cent of the dogs showed electrocardiographic evidence of protection

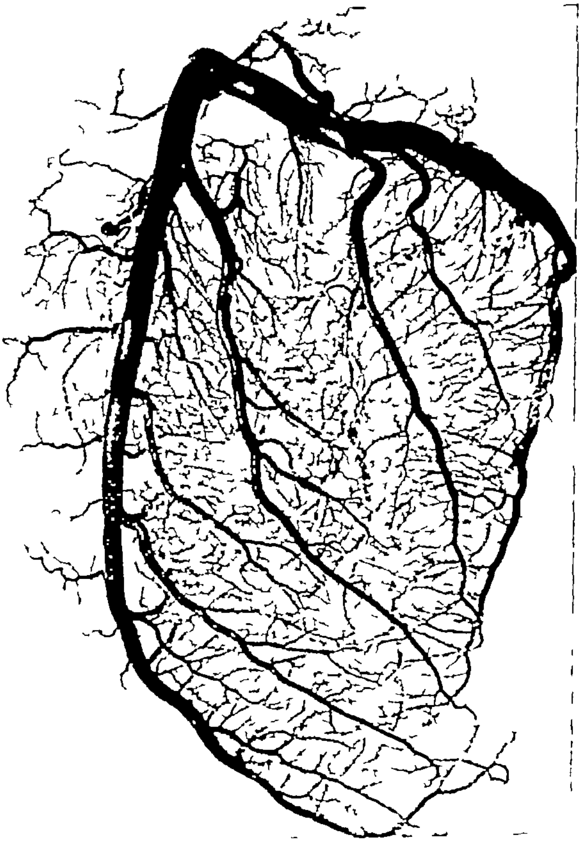

Fig 5 —Plastic cast of coronary artery system in a normal human heart Note the rich system of small vessels that were present within the substance of the myocardium No intercoronary communications were demonstrated

Most of the intercoronary communications which result from operation are present on the surface of the heart There exists, however, a rich system of small arteries within the substance of the myocardium (Fig 5) It was thought that the injection of a thin suspension of irritant into the myocardium might stimulate the growth of intercoronary communications between some of these vessels Ten dogs were studied (Fig 6) The average backflow was

6.08 cc. per minute. Sixty per cent of the dogs showed electrocardiographic evidence of protection. The postoperative morbidity in these dogs was high. Many of the dogs showed disturbances in cardiac rhythm. It was concluded that injection of the irritant into the myocardium was no more beneficial than the standard operation. It was also considered more dangerous because of the morbidity and rhythm disturbances.

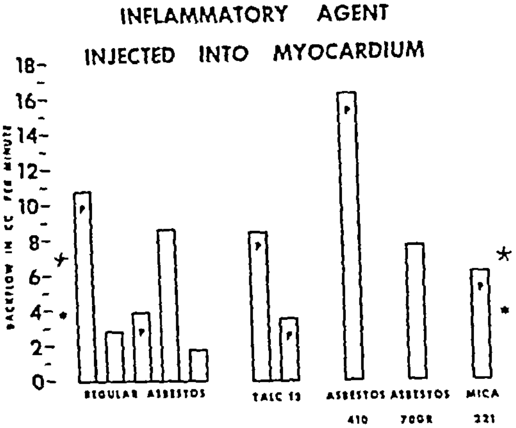

Fig. 6.—Each bar represents backflow from one dog. P indicates presence of electrocardiographic evidence of protection. The star indicates the average backflow for this group of dogs. The asterisk indicates the average backflow in control dogs.

Removal of the epicardium by chemical rather than mechanical means was tested. Fig. 7 shows the backflows obtained from dogs in which phenol, silver nitrate or urea was tested. There were 6 postoperative deaths, 35 per cent mortality in the group of 17 dogs. The postoperative morbidity was very high. The average backflow in the 11 surviving dogs was 5.2 cc. per minute. Chemical removal of the epicardium using the concentrations tested was a dangerous procedure. By testing various concentrations of chemicals a safe dosage might have been found. The results were not sufficiently encouraging, however, to warrant testing a large number of dogs in order to determine dosage.

Some surgeons have attempted to stimulate the growth of intercoronary and extracoronary communications by the application of an inflammatory agent to the surface of the heart without combining it with other mechanisms of benefit.[illegible] An example is the application of from 4 to 6 Gm. of talc to the surface of the heart. In a group of 22 dogs 4 Gm. of talc was applied to the heart. Several dogs developed compression signs with this dose of irritant. Two dogs died during the cannulation of the circumflex artery [illegible]. The dogs were not protected by operation. Fig. 8 shows the backflows obtained from the remaining 20 dogs and compares them with [illegible] Beck No. 1 operated dogs. The average backflow was [illegible]. Twenty-five per cent of these dogs showed electrocardiographic evidence of protection While application of talc alone elevated the average backflow above the average normal backflow by 1 1 c c per minute, the Beck No 1 operation elevated backflows by 4 7 c c per minute

Another attempt to improve the blood supply to the heart is the implantation of the internal mammary artery into the substance of the myocardium[15] Fig 9 shows the backflows obtained in 20 dogs in which the

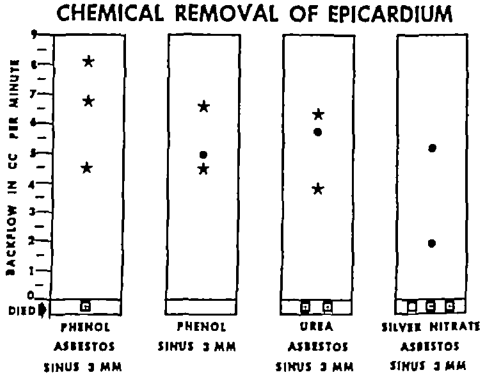

Fig 7 —Each dot or star represents backflow from one dog Each square symbol represents a postoperative death A star indicates the presence of electrocardiographic evidence of protection

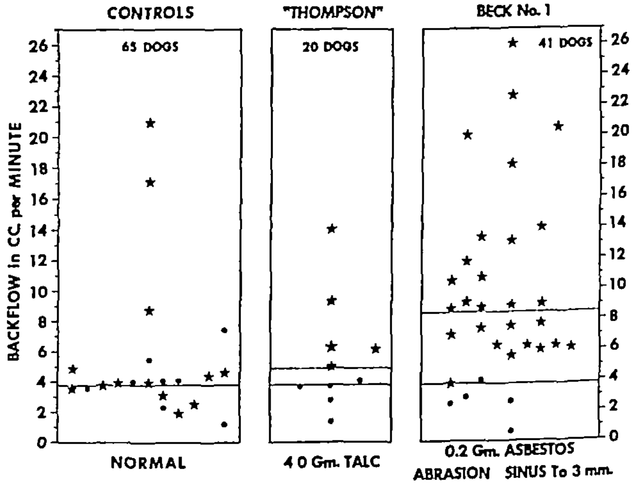

Fig 8 —Backflows in normal dogs compared to backflows from Beck No 1 operated dogs and dogs in which 4 Gm of talc was applied to the surface of the heart. Each dot or star represents the backflow from one dog A star indicates the presence of electrocardiographic evidence of protection The solid horizontal line is through the average backflow for control dogs The horizontal dotted line is through the average backflow for each group of dogs

mammary artery had been implanted No attempt was made to create a "physiologic need" by coronary artery occlusion If a coronary artery is ligated or its lumen is reduced to less than 1 mm, growth of intercoronary communications is stimulated Unless large quantities of blood were con tributed by the mammary artery graft it would be difficult to evaluate the function of the graft in the presence of these intercoronaries. In the dogs tested backflows were obtained from both the circumflex and descending coronary arteries with the mammary graft both clamped and not clamped. Any difference in backflows with the graft clamped and not clamped would represent the amount of blood contributed by the mammary artery graft. Any elevation above normal backflows obtained with the mammary clamped would indicate the development of intercoronary communications as a result of the operative manipulation. The graft was occluded by thrombus in 5 of the 20 dogs. In none of the dogs was there a difference in backflow from either the descending or circumflex artery with the graft clamped or not clamped. In none of the dogs was the backflow significantly elevated above the average backflow obtained from normal dogs. In 20 dogs the average backflow from the circumflex artery was 3.81 c.c. per minute and from the

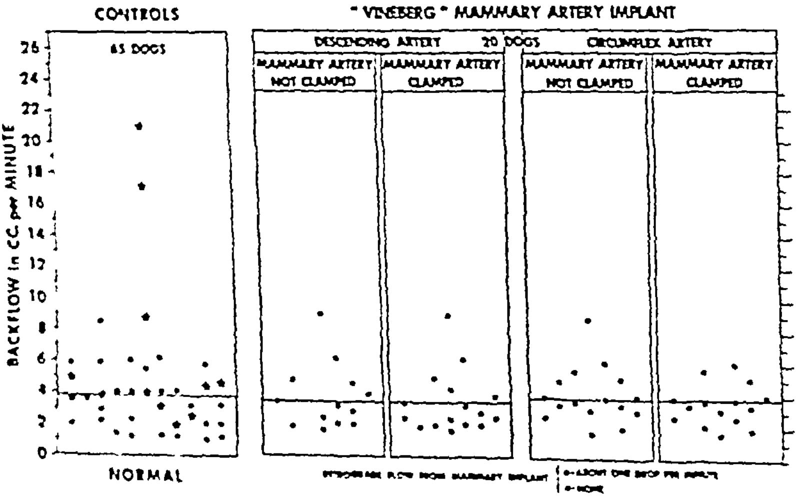

Fig. 8.—[illegible] compared to backflows in dogs in which the internal [illegible] implant [illegible] into the myocardium. Each dot, square or star represents [illegible] the presence of electrocardiographic evidence of [illegible] flow from the [illegible] mammary

descending artery was 3.5 c.c. per minute. None of the dogs showed electrocardiographic evidence of protection. After backflows had been obtained the [illegible] artery graft was cut between the heart and chest wall. In some [illegible] quantities of blood were seen to well up in the lumen of the [illegible] side. This indicates that communications with coronary [illegible] were present but in such a small degree that the amount of blood was [illegible]. [illegible] was estimated as in the range of 1 drop per [illegible]. It was concluded that under these conditions the internal mammary [illegible] contribute significant quantities of blood to the [illegible]

The Beck operations for coronary artery disease have been applied to 240 patients during the past twenty years. Since January, 1954, only the present version of the No. 1 operation has been applied to patients. This consists of abrasion of the epicardium and pericardium, partial sinus ligation, application of 0.2 Gm. of powdered asbestos to the surface of the heart, and application of grafts of tissue, consisting of the abraded pericardium and of mediastinal fat, to the surface of the heart. Seventy-five patients have been operated upon during this seventeen-month period. There were two deaths from thoracotomy alone, before anything was done to the heart, a mortality of 2.6 per cent. There were three deaths in the early postoperative period a mortality of 4.0 per cent. The total operative mortality was 6.6 per cent. During this time only two patients died subsequent to discharge from the hospital, a late mortality of 2.6 per cent.

The first-year late mortality has been calculated on the experience of 136 patients operated upon between 1935 and June, 1954. From time of discharge up to one year after operation there were 9 deaths, a mortality of 6.6 per cent. The second-year late mortality was calculated on the experience of 83 patients operated upon between 1935 and June, 1953. From one year up to two years subsequent to discharge there were 4 deaths, a mortality of 4.8 per cent. The total two-year mortality in patients treated surgically was 18.0 per cent (6.6 per cent operative mortality plus 6.6 per cent first year mortality plus 4.8 per cent second-year mortality). In 88 patients who were acceptable candidates for sympathectomy for relief of angina pectoris but who were not operated upon for nonmedical reasons[16] there were 15 deaths the first year, 17 per cent, and 11 deaths the second year, 13 per cent, for a total two-year mortality of 30 per cent under medical treatment. Mortality under surgical treatment for a two-year period was 18 per cent. In the laboratory where conditions can be controlled and made comparable it has been shown that operation reduces mortality. Probably no two groups of patients are strictly comparable, even if alternate cases were selected for operation. However, these groups may have some comparable significance and if so, it appears that a similar statement might be made concerning human patients.

In evaluating the results in patients, their pain and ability to work during the preoperative period have been compared to pain and ability to work in the postoperative period. Of 103 patients who were 6 months or more postoperative and who could be evaluated, 90 per cent have either no pain or marked reduction in pain and are better able to work. Some of these patients appear to be completely recovered from their symptoms. Others who have evaluated results in some of these patients have reported similar results.[1, 1]

These results place surgical operation in a favorable position for the treatment of coronary artery disease.

SUMMARY

1 The majority of deaths from coronary artery disease are due to unequal oxygenation of the myocardium resulting in electrical instability of the heart and a break in the coordinated mechanism of the heartbeat These hearts were presumably capable of continued function had not the heartbeat been destroyed

2 Intercoronary arterial communications if present can evenly distribute blood in the myocardium and prevent the development of electrical instability of the heart As little as 4 7 c c per minute of additional blood to the myocardium beyond an occlusion can save life and save myocardium from destruction

3 Operative manipulation of the heart stimulates the development of intercoronary arterial communications Intercoronary communications resulting from a variety of operative manipulations have been evaluated by the Mautz Gregg backflow method of study and the results presented

4 There is no experimental evidence to indicate that medical therapy adds or subtracts a single drop of blood to ischemic areas of myocardium The Beck No 1 operation however provides the equivalent of a transfusion of 282 c c of additional blood per hour to the myocardium beyond the occluded circumflex artery

5 The Beck No 1 operation relieves symptoms to a significant degree in nine out of ten patients The operative mortality is about 6 6 per cent The trend of experience indicates that operation prolongs life

6 Laboratory tests and clinical results place operation in a favorable position in the treatment of patients with coronary artery disease

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(For Discussion see page 432)

TECHNICAL FACTORS WHICH FAVOR MAMMARY-CORONARY ANASTOMOSIS

With Report of Forty-five Cases of Human Coronary Artery Disease Thus Treated

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AT THE last meeting of this Association the frequency of mammary-coronary anastomosis and mammary artery patency was questioned by one investigator. Because of this it seemed advisable to review our knowledge concerning internal mammary artery implantation and the factors which play a part in preventing occlusion of the implanted artery.

This question has been studied by us for ten years and our experimental data have been reported. Many hundreds of animals have been operated upon in testing one factor at a time. Today many of the factors responsible for occlusion of an implanted internal mammary artery are well known to us, as are some of the conditions which favor mammary coronary anastomosis.

Factors which affect successful transference of a chest wall artery into the myocardium where it may function as an extracoronary artery are as follows: (1) the method of detachment of the internal mammary artery from the chest wall, (2) the method of implantation into the left ventricular myocardium and (3) the condition of its myocardial environment.

In this article the technique of internal mammary artery implantation and the factors which seem to be responsible for keeping the artery open will be discussed together.

INCISION

With the patient in the right lateral position the incision is carried from the midline anteriorly to the paravertebral line in the fifth interspace posteriorly. The fifth or sixth rib is removed extraperiosteally depending on the preoperative fluoroscopic examination of the position of the apex. The rib below the apex is removed. If the thorax is resistant to lateral spread it [illegible] to cut the fifth or sixth rib posteriorly, otherwise there is a tendency [illegible] sixth costochondral junction to separate. Six cubic centimeters [illegible] procaine hydrochloride is injected into the pericardial sac and [illegible] around during the preparation of the artery. The sterno[illegible] is [illegible] removed from the fourth to sixth costal carti[illegible] the internal mammary artery and vein.

[illegible]

maintenance of this precise balance during the period of intracardiac surgery. To obtain this critical balance, we have continued to use the single headed pump and have maintained equality of flow in both circuits through the use of special adaptors on each line.[18] By means of these, the tension, and hence the internal diameter of the rubber tubing within the pumping mechanism, can be varied; this, in turn, varies the output of the pump. Minute changes in flow can be obtained and balance of the two circuits within 1 c.c. in five minutes maintained. In spite of proper preoperative balance, imbalance during surgery may occur due to obstruction of either intake catheter, especially in the superior and inferior venae cavae. To minimize the incidence and the grave consequences of such a complication, blood reservoirs have been inserted in both circuits. The reservoirs are constructed to eliminate the marked negative pressure effect of the pump at the intake catheters which, previous to the use of the reservoirs, contributed to the collapse of the cavae about the intake catheter, thus throwing the circuits out of balance and leading to possible exsanguination of the donor. Instead of drawing blood directly from the recipient and donor, the pump now draws blood from the two reservoirs and a constant flow of blood to each person is assured by the maintenance of the blood level in the reservoir. In addition, with this system either person can be selectively transfused with a measured quantity of blood at a rapid rate. Through the incorporation of such a reservoir on the donor-to-recipient circuit, the variable effect of the blood pressure head in the donor on blood flow rates from donor to recipient has been eliminated.

Another source of imbalance of the two circuits may be the rapid loss of blood in the recipient, or operated person. Because of distortion of the aortic annulus in the open, collapsed heart, or because of the associated aortic valve defects, the regurgitation of blood through the aortic valve, and hence through the ventricular septal defect may be so copious at times as to obscure the operative field completely. This regurgitation may be eliminated for a short period by the intermittent occlusion of the ascending aorta by an encircling ligature while stitches are being placed in the ventricular septal defect. It has not been established how well the diseased heart will tolerate such intermittent coronary inflow stasis. In the laboratory animal, it appears that the coronary arteries can be occluded safely up to two minutes. To compensate for these periods of coronary artery occlusion, we have been following such periods of ascending aortic occlusion by occluding the descending aorta in order to increase temporarily the pressure in the aortic arch and increase the coronary flow. It is felt that this additional boost of coronary blood following complete stasis has been beneficial. An alternate method of placing the ligature on the ascending aorta below the coronary arteries is being explored at the present time. This, of course, will allow continued coronary flow during the periods of aortic occlusion. Perhaps occlusion of the aorta in this area will hamper proper closure of the ventricular septal defect.

In spite of these added safeguards, we feel that it still would be beneficial to have an efficient, but not too complicated, flow meter incorporated in each circuit so that the exact rates of blood flow in both persons would be known in any given instant Such a flow meter is being developed at the present time

A suitable donor was not available in 3 of the first 6 patients we considered for surgery utilizing cross circulation Looking for a way to eliminate the donor in such instances it was decided to investigate the possibility of substituting a large reservoir of oxygenated blood for the donor individual In small patients with flow rates of 30 to 40 c c per kilogram per minute 10 to 20 liters of oxygenated blood would be sufficient This was investigated and found to be successful in the laboratory and was tried on one clinical case This patient developed ventricular fibrillation as soon as the ascending aorta was occluded and a normal rate could not subsequently be restored

At the present time the technique of controlled cross circulation is not applicable to adult patients requiring open intracardiac surgery Possibly the use of oxygenated blood reservoirs can be utilized in spite of the fact that a large person will require a large volume of blood even at basal flow rates

CLOSED TECHNIQUES

Because of the inherent difficulties previously discussed in the presently available open techniques, means of repairing ventricular septal defects by "closed techniques" are continuing to be sampled All these techniques utilize the principle of approximating the pliable myocardial wall between the aorta and right atrium to the lower edge of the septal defect

Closure of ventricular septal defects by the closed method are best approached through a right anterolateral incision through the third or fourth interspaces with transection of the sternum if necessary The superior and inferior venae cavae should be isolated and an encircling tape put in place to provide for temporary vena caval inflow stasis in the event of hemorrhage from the hypertrophied right ventricle or to allow temporary collapse of the right ventricle for easier approximation of the edges of the defect Three variations of the closed technique have been employed experimentally and will be referred to as Types I II and III A ventricular septal defect is first produced beneath the septal leaflet of the tricuspid valve simulating as much as possible those defects found clinically Such defects frequently interrupt fibers of the bundle of His and conduction arrhythmias usually result

In Type I (Fig 5) a purse string suture is placed in the anterior border of the right ventricle in such a position that a large, blunt-nosed curved needle can be introduced alongside the finger in the same opening The intracardiac finger retracts the septal leaflet away from the defect The end of the needle first engages the apical surface of the defect care being exercised not to include either the crista supraventricularis or the chordae tendineae The needle is then passed upward between the annuli of the tricuspid and aortic valves and exits through the myocardium proximal to the aortic valve at its junction with the right auricle The right auricular appendage is retracted laterally The other end of the suture is then threaded and passed in a similar manner so that a mattress suture is so placed A small piece of pericardium is placed on this suture and

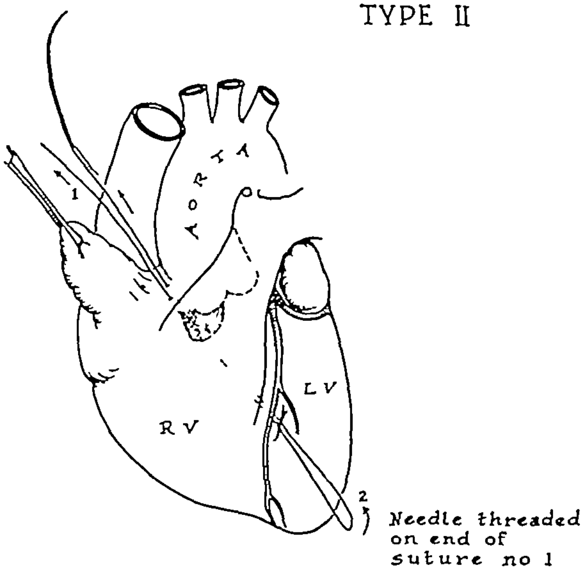

Fig 6 —Diagrammatic sketch of Type II method for closure of ventricular septal defects Similar to Type I except for introduction of suture along course of ventricular septum Direction and position of suture is determined by the intracardiac finger (see text)

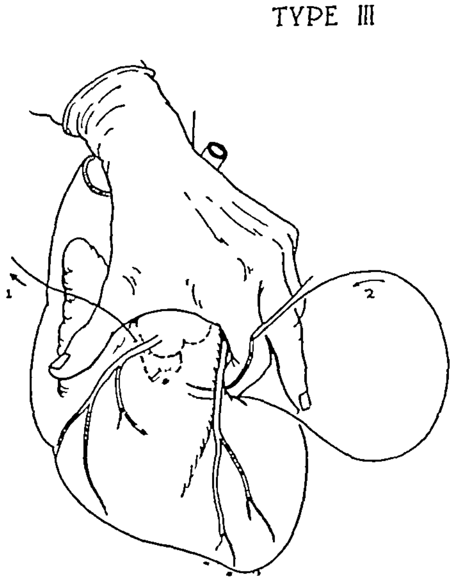

Fig 7 —Diagrammatic sketch of Type III method for closure of ventricular septal defects Similar to Type I except for the approach through the left ventricle rather than the right ventricle

slid down to the septal edge, so that the stitch is less likely to tear out Two to three such sutures appear adequate to close the defect The sutures must be placed in a longitudinal manner, rather than transversely, so that the outflow tract of the left ventricle is not encroached upon The sutures exit posterior to the right coronary artery The assistant then ties the sutures outside the heart, over a piece of pericardium, the degree of tautness being determined and directed by the operator s intracardiac finger This appears to be an effective way of closing such defects

Type II (Fig 6) consists of directing a suture through the ventricular septum The needle is introduced just to the left of the descending coronary artery, and is directed by the intracardiac finger to engage the apical edge of the defect and to exit as in the preceding technique The other end of the suture is threaded and passed in a similar manner The anterior sutures are passed through the pericardium and the ends of the suture are tied over a section of pericardium to lessen the possibility of the sutures pulling through the myocardium Because of the relationship of the direction of the suture in relation to the defect, there is a tendency for the suture to pass through the defect in a diagonal manner so that when the sutures are tied there may be some impingement on the aortic outflow tract This is lessened the further toward the apex the sutures are introduced anteriorly

In the Type III approach (Fig 7) the ventricular septal defect is closed in a manner similar to Type I, but through a left myocardiotomy opening Theoretically and experimentally, this appears to be a simpler approach, for one does not have to contend with the chordae tendineae and tricuspid leaflets on the left side Practically, however such an approach would be difficult because of the inaccessibility of the left ventricle in the presence of a hypertrophied right ventricle

RESULTS

Although total experience in terms of patients has been small and the results in terms of survival have not been outstanding the benefits to those involved in perfecting techniques for the closure of ventricular septal defects have been outstanding To date closure has been attempted in only 6 patients —2 by closed techniques and 4 by open techniques The 20-year-old girl who underwent repair of a ventricular septal defect by closed technique in 1953 is living and well at the present time Although a murmur is still present, her right ventricular pressure has dropped from 80/3 mm Hg preoperatively to 40/4 mm Hg postoperatively The second patient in whom a closed technique was employed died of ventricular fibrillation at the time of surgery Three patients have been operated upon utilizing the controlled cross circulation with one successful closure One patient died postoperatively after a successful closure and the other patient died at the time of operation from excessive regurgitation of blood through the aortic valve and septal defect as described previously There have been no donor deaths although in the last case the donor suffered a large blood loss consequent to excessive blood loss in the recipient One patient was operated upon by the open method employing a pump and a reservoir of oxygenated blood This patient had an extremely large defect in a markedly hypertrophied heart

DISCUSSION

Obviously, the surgical repair of ventricular septal defects is not a closed chapter The technique of controlled cross circulation and the substitution of a large reservoir of arterialized blood in place of the donor individual probably offers the best approach to intracardiac surgery at the present time The use of hypothermia has been disappointing The perfection of an adequate pump-oxygenator probably will supply the ultimate answer In the meantime, invaluable experience and knowledge are being gained by utilizing available techniques

We feel strongly that the means of closing ventricular septal defects by closed techniques should receive continued investigation, for, if effective, they are generally simpler than open techniques In such closed techniques, it is felt that the principle herein described, of reconstituting the membranous ventricular septum by inversion and approximation of the pliable cardiac wall between the right atrium and aorta to the apical portion of the defect, holds promise

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DISCUSSION

DR G S CAMPBELL Minneapolis, Minn —Human blood has been perfused through the isolated dog lung for as long as two and one half hours at a flow rate of 500 to 1 000 c c per minute

(Slide) In order to minimize or prevent the development of pulmonary edema in the isolated lung, the following factors seem important (1) heparinization of the dog prior to removal of its lungs (2) open pulmonary veins to prevent back pressure (that is the pulmonary veins are not cannulated) (3) depulsation of pulmonary artery limb of the circuit to avoid high systolic pressures in the pulmonary circulation (4) ventilation of the lung with a pressure of 16 to 20 cm. of water avoiding expiratory resistance and (5) perfusion of large amounts (2 000 to 2.500 c c) of dextran through the lungs at a low pulmonary artery perfusion pressure (mean pressure less than 20 mm Hg) to rid the lung of residual blood. An advantage of the "open" system as depicted here is the ease with which arterial return to the subject can be equated with venous aspiration from the subject This balance is maintained by monitoring the level of blood in the plastic lung chamber if this blood level falls, one knows that he is returning more blood to the subject than he is aspirating from the subject and the opposite is true if the blood level rises

(Slide) This shows the isolated lung Note the plastic cannula in the main pulmonary artery the large tube in the trachea, and the open pulmonary veins

(Slide) Note the whitish color of the lung after it has been perfused with dextran

(Slide) This photograph shows the lung being perfused with human blood, and I believe that the wide A V oxygen difference is quite apparent

Cardiac bypass has been performed in four patients utilizing this type of pump biologic oxygenator, the longest bypass period being forty nine minutes The only long term survivor among the four patients is a 123 pound boy with a traumatic I V S D The three patients who died were (1) a child with tetralogy of Fallot severe overriding of the aorta in whom the I V S D could not be successfully closed surgically (2) an adult with left ventricular aneurysm and mitral disease who died during the operative procedure and (3) a child with I V S D with reversal of the shunt, that is, predominantly a right to left shunt The method has worked well in all cases The blood leaving the isolated lung is fully saturated with oxygen and no abnormal sequelae directly attributable to the bypass method were noted in the two short term survivors or the one long term survivor

In view of the success of the method per se, we plan to use this method in more patients and in better operative risks Following the use of the pump-biologic oxygenator no hemorrhagic diathesis has been noted bleeding and clotting times are normal

DR MELVIN M NEWMAN Brooklyn N Y—The team working in Dr Clarence Dennis laboratory at the State University of New York has perfected a successful heart lung machine which has been used experimentally for the creation and repair of atrial and ventricular defects under direct vision The details of the apparatus were described most recently at the Society of University Surgeons meeting at Houston in February

(Motion picture) Here is the outflow tract of the right ventricle The animal is on total perfusion with the heart and lungs completely bypassed The pulmonic valve can be seen up here and the tricuspid valve down below Ventricular defects were made in two ways (1) by the cork borer technique of Kay, Thomas, and Blalock or (2) by direct incision of the septum by a scalpel A finger could be passed readily into the ventricle through the defect

Blood flows in the animals were maintained at between 300 and 1,700 ml per minute There were 12 survivors of the 14 animals in which ventricular septal defects were produced and repaired Some derangement of the blood clotting mechanism occurs infrequently after perfusion and remains unexplained

DR J C CALLAGHAN, San Francisco, Calif—In considering the problems concerned with the closure of intraventricular septal defects, I would like to tell you briefly of an approach that Dr Gerbode and I have been testing experimentally in the laboratory at Stanford University in San Francisco We have been impressed with the difficulties of maintaining an extracorporeal circulation, without complication, in smaller animals and we believe that in the future pump oxygenator systems might be more difficult to manage in the infant and small child We wish to compliment the Minneapolis group on the successful clinical application of cross circulation to this problem In the long run, however, another simpler manner of maintaining the circulation for short periods of time must be found To reduce this to its simplest form, we are in the process of developing a form of reservoir circulation which will function without using a pump We have been able to perform ventriculotomy in the dry heart, using gravity alone to maintain pressure in the systemic circulation The venous blood used in these experiments was oxygenated in specially constructed plastic bags

(Slide) In other experiments in which we wished to have a greater outflow, we have omitted the gravity effect to see if we could, by just squeezing the plastic bag, maintain circulation adequately, and again we found that we were successful in maintaining circulation simply by using gentle compression of the transfusion bag by the human hand to develop the required pressure

(Slide) This shows the rate of oxygenation of blood by simple agitation with an oxygen bubble in a plastic bag, showing that 85 per cent saturation is obtained from venous blood at the two minute level and that all saturations were over 90 per cent at the end of four minutes, at the end of ten minutes all were about 93 per cent saturation Satisfactory saturations at four minutes of agitation allow the use in the circuit of caval outflow blood collected in plastic bags containing oxygen, extending the time element after an initial four to five minutes' dependence on the reservoir blood alone We have used this experimentally as a method of oxygenating blood

The next slide shows an experiment in which we were able to maintain systemic pressure of 80 to 100 mm Hg in a dog by arterial flow from a plastic bag The upper portion of the graph shows the effect of taking pressure off the plastic bag and changing from bag No 1 to bag No 2 Each transfusion bag contains the amount of blood calculated at 25 to 30 c c per kilogram of body weight for one minute of circulation Two bags may be emptied in a one minute period, but this represents the upper limit of flow, approximately one liter per minute Using low flow rates that have proved successful in clinical cases by others using controlled donor circulation, we feel that this method could be used on small children ideally and projected to children weighing up to 20 kilograms, approximately 5 to 6 years of age We present this as a simple method of approaching this very complex problem, and as yet it is too early to evaluate

DR C WALTON LILLEHEI, Minneapolis, Minn—Direct vision for intracardiac surgical procedures improves the quality of the surgery performed, and for this reason it appears likely that the blind techniques will be progressively discarded I am happy to see our former colleague, Dr Cross, as well as Drs Kay and Zimmerman, in the vanguard of the groups making this transition from blind to open intracardiac techniques

It was just one year ago, at this meeting, that our group reported the first successful closures of ventricular septal defects We utilized direct vision suture closure of these defects with total bypass of the heart and lungs, maintaining the patient during this interval by means of controlled cross circulation Physiologically, this technique has proved to be superb, for once the circulatory systems of the patient and the donor have been linked together, and the patient has been assured of a continuous supply of oxygenated and otherwise perfectly adjusted blood from his donor It is unlikely that a technique for total cardiac and pulmonary bypass will be developed that, for the patient's safety, excels this one In utilizing cross circulation, however, one must be prepared to accept responsibility for the well being of the normal, healthy donor

(Slide) To date, 41 patients have had their heart and lungs totally bypassed for periods of from five minutes to forty minutes, utilizing the technique of controlled cross circulation The clinical use of this method has been confined entirely to complicated septal defects, either ventricular or ventricular pathology associated with atrial defects These 41 patients include our entire experience with this technique There has been no donor mortality, and only one serious donor complication, previously reported, with complete recovery

All operations have been done at normal body temperatures to obviate the crippling effects of hypothermia upon ventricular conduction Systemic perfusion of the patient has been carried out at substantially reduced rates of flow (one eighth to one fourth of the normal resting cardiac output) based upon the azygos flow experimental studies There has not been a single instance of cerebral, hepatic, or renal dysfunction attributable to these low flows Appreciation of this low flow concept, because of the simplifications in methods made feasible, has been the most important single factor responsible for this progress Twenty five patients have had ventricular septal defects closed, with seven deaths Preoperatively, all these patients have been seriously ill, and have had pulmonary hypertension. The pulmonary pressures for the entire group averaged 75 per cent of their systemic pressures The first five patients have now been recatheterized four to nine months after corrective surgery, and in all five (100 per cent) there has been complete correction of their shunts The pulmonary pressures in three of these five patients have already returned to normal Numbered among these patients proved cured by recatheterization and with normal pulmonary artery pressures now is a 5 year old girl who weighed 11 kilograms at the time of surgery and who had severe pulmonary hypertension due to three separate ventricular defects Six of the seven deaths have been in infants, but of the 16 seriously ill infants operated upon, 10 were successfully treated There have been no deaths due to ventricular fibrillation, complete heart block, air embolism, hemolysis, or hemorrhage

Our next largest group subjected to direct vision curative procedures consists of patients with Fallot's tetralogy In this group, 10 patients, all consecutively operated upon, have had their ventricular septal defects closed and their infundibular pulmonic obstructions resected, with four deaths All six survivors have normal color and normal femoral artery oxygen saturations, and are asymptomatic postoperatively The first two patients have now been recatheterized, and one patient still has a small left to right shunt high in the right ventricle, the other boy has completely normal oxygen contents and pressures on right heart catheterization Preoperatively, this latter boy, a desperately ill 15 month old infant, had a femoral artery oxygen saturation of 25 per cent, which is now 95 per cent Also numbered among the cases successfully managed by these curative techniques are a 22 month old girl with complete atresia of the main pulmonary artery and a 10 year old boy with tetralogy of Fallot in whom simultaneous atrial and ventricular cardiotomies were performed for correction of his defects

As a result of these gratifying experiences, the curative operation has been adopted in our clinic as the method of choice for all patients with the tetralogy of Fallot defect who are in need of surgery at this time For lesser degrees of disability, we recommend no surgical operation at this time but, rather, periodic re evaluation in the clinic

Time does not permit a discussion of the remaining types of defects successfully managed by these techniques, but I will call your attention to the fact that the atrioventricularis communis defect, contrary to some published opinions, is a correctable defect The first patient (15 months old) with this defect has now been recatheterized postoperatively, no shunt remains and the pulmonary artery pressure has decreased from a preoperative high of 90/50 mm Hg to 20/4 mm Hg This child is also normal clinically

The value of relying upon a simple physiologic method for intracardiac surgery is attested to by the fact that the last 14 consecutive cross circulation curative operations, all carried out in seriously ill infants or children with ventricular septal defects or tetralogy of Fallot, have been performed with only one death

Moreover, these experiences have led to the development, at our institution of two other simple techniques for total cardiac bypass based upon these same general principles, but neither of which requires a donor Each of these two techniques has permitted successful direct vision repair of ventricular septal defects in man. These two methods are (1) the use of a heterologous lung oxygenator, described by Dr Campbell, and (2) the use of continuous perfusions by means of arterialized venous blood from a reservoir, to be described in tomorrow's program by Drs Warden and Read

In closing, I should like to emphasize that the feasibility and practicability of the direct vision approach to intracardiac lesions is so convincing that I would venture the prophecy that coming months will see a progressive increase in its application, not only in congenital heart disease, but also for acquired heart lesions, eventually replacing blind techniques with few exceptions and making surgical management possible for conditions now quite hopeless

DR EARLE B KAY, Cleveland, Ohio (Closing) —Sufficient evidence has now accumulated to demonstrate that ventricular septal defects may be a serious threat to life With the more precise diagnostic method afforded by cardiac catheterization and the greater interest in carefully following such patients, the progressive disability noted by many such patients becomes obvious Efforts should be directed, at the present time, to determining the exact indications and contraindications to surgical therapy, the optimum age for treatment and to perfecting surgical techniques

There are many aspects of the problem that cannot be duplicated in the laboratory The purpose of our paper was to present our clinical and experimental experience in the closure of such defects employing various techniques and to illustrate the manner in which the defects are most effectively closed Undoubtedly, several methods for closure, dependent primarily upon the size of the patient, will be evolved

With reference to Dr Newman's motion picture, I would like to point out that the myocardiotomy is better placed if directed from the atrioventricular ring to the apex, rather than through the pulmonary outflow tract so that significant coronary vessels are not severed with resultant myocardial ischemia

Also, as pointed out in the paper, the method shown by Dr Cooley of placing the suture through the ventricular septum is likely to close the defect in a diagonal manner which results in incomplete closure and likely partial occlusion of the aortic outflow tract.

EXPERIENCES WITH SURGICAL REPAIR OF ATRIAL SEPTAL DEFECTS

Elton Watkins, Jr , M D and Robert E Gross, M D
Boston, Mass

SURGICAL closure of congenital defects in the atrial septum has proved to be a useful procedure which benefits severely incapacitated patients Our experience with the operation over a period of three years since 1952 has permitted the evolution of a number of refinements contributing to the ease of management of this condition. The refinements have been reflected in a falling morbidity rate In the last fourteen months, mortality has been due exclusively to advanced complicated disease The present communication describes the manner in which these changes have occurred

PRESENT INDICATIONS FOR OPERATIVE REPAIR OF A DEFECT

Clinical and laboratory findings leading to a diagnosis of atrial septal defect have been reported previously by others[1] Our present indications for operation were selected early in our experience when it was obvious that the procedure was risky because of unsolved technical problems The indications were (a) persistence of incapacitating symptoms despite optimal medical management, (b) persistence of serious cardiac enlargement and pulmonary congestion, or (c) catheterization evidence that right ventricular output was more than twice left ventricular output By such indications patients were selected who had either severe limitation of activity or signs of impending difficulty due to enormous shunting through the diseased septum

The use of catheter evidence of a great shunt has been strengthened by our recent experience with several adults in early middle life These patients have tolerated enormous shunts without serious trouble through their early years only to develop intractable congestion as cardiac reserve diminished They have had a stormy postoperative convalescence Improvement of exercise intolerance has not been as rapid as in the younger patients Whenever a large atrial septal defect is suspected cardiac catheterization should be performed to obtain precise figures as to the magnitude of the shunt so that operative closure of the defect can be accomplished before serious congestion develops

We have derived useful information from the calculation of systemic blood flow pulmonary blood flow and shunt blood flow Although the figures are probably only rough estimates they are accurate enough to give valuable clinical

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From the Department of Surgery of the Harvard Medical School and the Surgical Service of the Children's Medical Center Boston

Aided by Grants from the National Heart Institute United States Public Health Service

Read at the Thirty fifth Annual Meeting of the American Association for Thoracic Surgery at Atlantic City N J April 24 26 1955 information about the volume of shunting and the existence of pulmonary vascular obstruction Most individuals with large defects will show elevated pulmonary artery pressure despite normal pulmonary vessels because such large volumes of blood are being forced through the normal vascular bed These patients must be differentiated from the rare individual who has actual anatomic constriction of the pulmonary arterioles The differentiation can be made only by the calculation of pulmonary blood flow and calculation of the ratio of blood pressure to blood flow in the lungs

We have also found it useful to correlate the volume of shunting, as calculated from catheterization figures, with the x-ray evidence of pulmonary congestion and cardiac enlargement When the volume of shunting is large but the lungs are not seriously congested and the heart is not greatly dilated, the patient tolerates operation well because the heart is still compensating efficiently for the increased burden In contrast, the individual with serious pulmonary engorgement and cardiac dilation, but with a shunt flow of smaller magnitude, tolerates operation poorly and develops peculiar cardiac difficulties after repair

The presence of harsh systolic murmurs along the lower sternum has been a danger signal to us indicating the existence of either a low-lying defect (the so-called "ostium primum" defect) with associated tricuspid and mitral valve deformity or a ventricular defect with tricuspid valve insufficiency Catheter studies cannot usually differentiate these malformations from the higher defects amenable to surgical closure

PREOPERATIVE MANAGEMENT

These individuals present all gradations in the severity of congestive heart failure We have not seen a patient with an uncomplicated defect whose condition could not be improved to the point of good compensation for the period of surgical intervention by such conventional measures as the limitation of fluid and sodium intake and mercurial diuresis We have not hesitated to give digitalis in the preoperative period but only for clear-cut indications of congestive heart failure We prefer to discontinue digitalis for several days immediately prior to operation because we have had fatal asystole in other types of patients on digitalis who had received calcium injections at the time of operation Calcium has proved valuable in counteracting the transient myocardial weakness observed frequently during repair of the defect, and we would like to use it without the danger of synergistic action between calcium and digitalis

Antibiotics have been given to suppress respiratory infection We have not seen serious nutritional deficiencies The poor body development in these patients is probably related to a deficient left ventricular output and has not been influenced by special diet Small doses of quinidine have reduced the incidence of cardiac arrhythmias during operation The drug has been continued after operation for several weeks

TECHNICAL PROBLEMS AT OPERATION

Following development of the atrial well operation, it became evident that the majority of defects we saw could be closed by a simpler method of suturing from the outside surface of the intact atrium Our technique and experience with both methods have been described in detail[2, 3] We now plan to reserve the use of the atrial well for those malformations which cannot be closed by the external suture technique because of either large size or anterior position in the septum In our hands the well has proved to be a versatile method for handling such defects but in our last 30 patients only 3 defects were types which would have required use of the atrial well In one of the patients an error was made in not applying the well Death followed attempted closure of a large defect In the other two patients associated tricuspid regurgitation resulted in such a high atrial pressure that the well could not be applied Commonly the defects we have seen have been located high and posterior in the atrium near the root of the right pulmonary

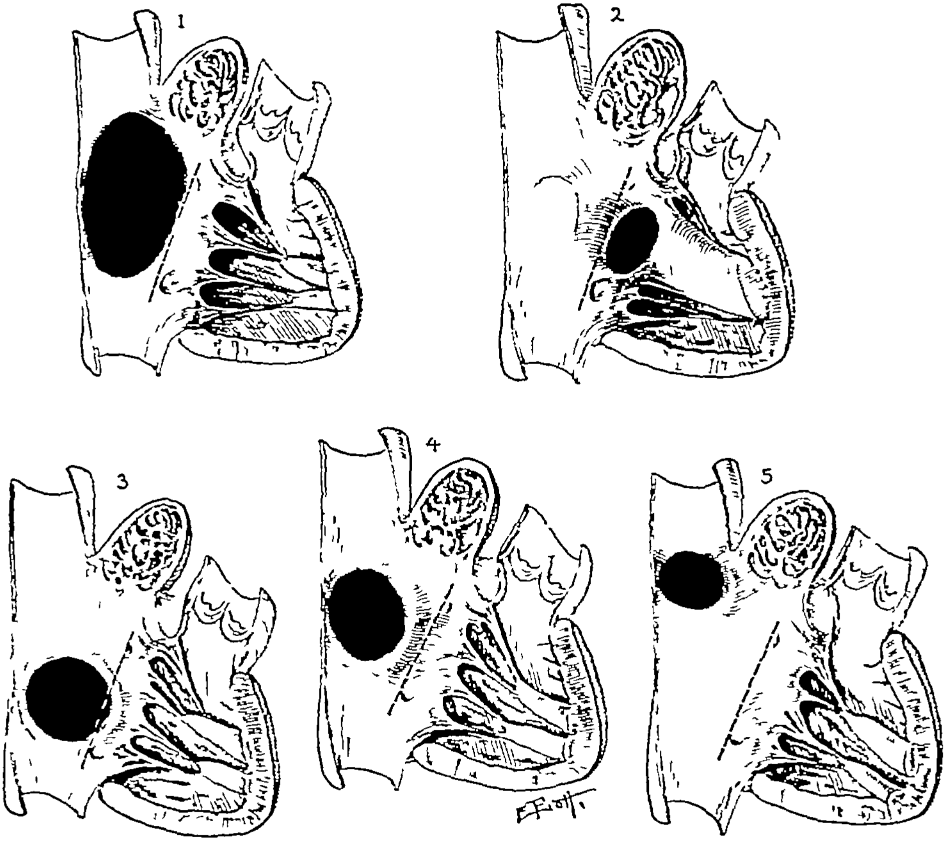

Fig 1 —Classification of the types of atrial septal defect found in 43 operations *1* Common atrium (2 cases) *2* Endocardial cushion defect (4 cases) *3* Inferior defect (5 cases) *4* Mid atrial marginal defect (17 cases) *5* Superior marginal defect (15 cases) The dotted line passing between the coronary sinus and the central fibrous body serves to locate the atrioventricular conduction system.

veins The preponderance of dorsal defects has led us to develop a simple classification of surgical anatomy Each class presents unique characteristics and problems in surgical management

SURGICAL ANATOMY OF ATRIAL SEPTAL DEFECTS

Although the 43 defects evaluated at operation have varied greatly in size and shape, they tended to fall into five general categories, depending upon their location in the septum (Fig 1) Certain orifices have been multiple or slit shaped but surgical management was similar to the repair of a solitary oval defect in the same location

1 *Common Atrium*—In this heart the septum was absent except for small ridges along part of the margin of the common atrial chamber There was no deformity of the atrioventricular valves This type of malformation was present in 2 out of the 43 cases

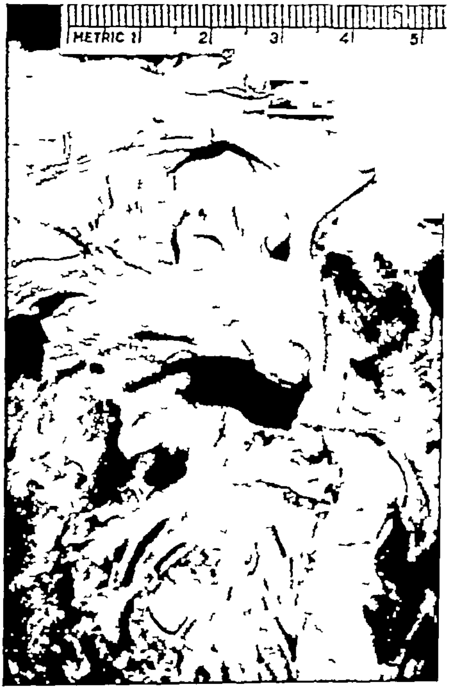

Fig 2—Right atrial view of an endocardial cushion defect. The defect is located at the base of the tricuspid valve The septal cusp of the valve is absent. Superior to the defect there is an incompletely closed *foramen ovale*

2 *Endocardial Cushion Defect* (the so-called "ostium primum" defect) —This defect was located anteriorly in the atrial septum immediately above the tricuspid and mitral valves In every defect there was an associated deformity in the valve cusps below the defect The defect was characteristically small, measuring from 1 5 to 2 5 cm in diameter It was frequently separated from the upper atrial septum by a prominent ridge of tissue so that the orifice entered

into a small vestibular chamber isolated from the main cavity of the right atrium. Above this diminutive antechamber, a foramen ovale was found, frequently bearing a second defect (Fig 2)

We prefer to classify this defect as one of the endocardial cushion because it is related not only to inadequate fusion of the primitive atrial septum with the endocardial cushions (the anlage of the mitral and tricuspid valve rings) but also the incorrect maturation of the endocardial cushions themselves This maldevelopment results in serious atrioventricular valve deformity and regurgitation We have seen this defect 4 times in the 43 cases Each time it has been associated with deformities of both the mitral and tricuspid valves Although we have been able to close some of these defects surgically cardiac failure and death have promptly supervened We question the wisdom of at-

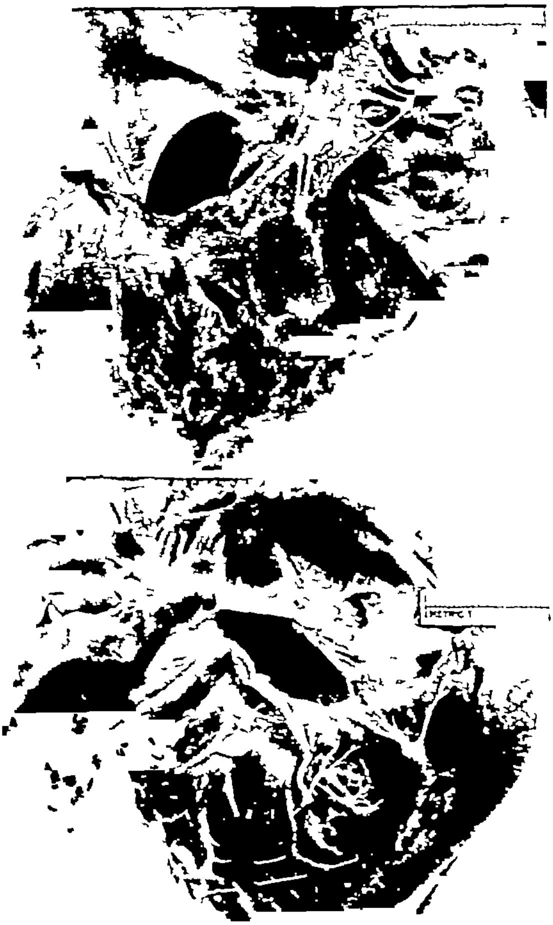

Fig 3—Right atrial view (top) and left atrial view of an endocardial cushion defect. The septal cusp of the tricuspid valve is fenestrated There is a V shaped defect with wide incompetency of the mitral valve

tempting to convert the left atrium into a small closed chamber into which blood regurgitates without any passageway for decompression through the surgically closed defect

Dissection studies of the atrioventricular conduction bundle indicate that this specialized tissue makes up the inferior margin of the endocardial cushion defect Animals have commonly shown serious conduction disturbances and death when this bundle was traumatized with needles or cut

The endocardial cushion defect should be differentiated at the time of operation from the following type of defect, the inferior defect, which it closely resembles The inferior defect presents an entirely different picture in the ease and value of surgical closure

3 *Inferior Defect*—The inferior type of defect was located close to the inferior caval orifice The right atrial chamber is shaped like an inverted cone with a broad superior surface bearing the superior caval orifice and the right atrial appendage Inferiorly the caval orifice extends through the full diameter of the narrow chamber Consequently, defects low in the septum near the inferior caval orifice extended through the full diameter of the chamber and lay in close juxtaposition to the tricuspid valve ring and coronary sinus They resembled the endocardial cushion defects in position, but there were certain important differences (a) the atrioventricular valves were fully developed and valvular incompetence was not apparent, (b) the defects were larger than the endocardial cushion defects, ranging in diameter up to 4 0 cm , (c) there was no evidence of a *foramen ovale* or *fossa ovalis* palpable superior to the defect, (d) there was no evidence of tissue ridges or antechamber formation superior to the defect

The adequate development of the atrioventricular valves is of considerable significance to the surgeon since there is no valvular regurgitation which might contraindicate the conversion of the left atrium into a high pressure chamber without outlet through the defect The well-developed annular rings form a broad shelf suitable for the placement of secure sutures

As the surgeon palpates these defects of the inferior type, certain features allow differentiation from the endocardial cushion defect (a) large size, (b) absence of regurgitant jets at the mitral and tricuspid orifices, (c) a smooth residual septal surface above the defect without fossa ovalis or prominent ridges The absence of a separate fossa ovalis suggests that this defect results from imperfect development of the *septum secundum* during embryonic life

The inferior defect does resemble the endocardial cushion defect in its close proximity to conduction tissue in the tricuspid valve ridge We have been able to close these defects with a feeling of safety only after certain landmarks were found which allow the surgeon to guide sutures away from the node tissue

We have seen the inferior type of defect 5 times in our 43 cases Hence it tends to be about as common as the endocardial cushion defect

4 *Mid-atrial Marginal Defect*—The commonest type of defect we encountered was one located near the posterior margin of the atrial septum adjacent to the roots of the right pulmonary veins about midway between the two caval orifices It was present 28 times in our 43 cases The close

proximity to the dorsal margin of the atrium and the position well away from the caval orifices render these defects particularly suited to closure by the external suture techniques Difficulties in surgical closure stem from the large size of the defect (up to 4 0 cm in diameter) and the thin friable character of the anterior remnant of septal tissue

5 *Superior Marginal Defect*—Next to the mid-atrial marginal defect, this deformity was the most common It has been present in 15 of our 43 cases The lesion tended to be smaller than the mid-atrial marginal defect and lay in close proximity to the superior caval orifice External suture closure must be made in such a manner that occlusion of the superior cava is avoided We have seen no arrythmias suggesting injury to the sinoauricular node during closure of these defects and have not carried out anatomic studies locating the structure

Major associated conditions have been divided sharply among the types of defects True pulmonary vascular obstruction has been seen only with the mid-atrial marginal type of defect Possibly the large size of this malformation results in tremendous blood shunting early in life thus predisposing to pulmonary vascular obstruction Anomalous drainage of the right pulmonary veins into the right atrium has been seen only with defects of the inferior and superior marginal types The eccentric position of the defect in relation to the mid-atrial location of the anomalous vein orifices presents some difficulty in surgical management Deformities of the mitral and tricuspid valves have been present only in defects of the endocardial cushion type The inferior type of defect differs from the endocardial cushion defect in the absence of valve deformity, but resembles it in the proximity to the valves and atrioventricular nodal tissue

Lesions suitable for closure by the external suture method have been the inferior, mid-atrial marginal, and superior marginal defects The endocardial cushion defect may prove suitable for closure by external suture but the associated valve deformity introduces serious problems after closure The common *atrium* type of defect would seem to require some type of prosthesis or tissue graft to avoid atrial and valve-ring distortion The occurrence of the inferior type of defect, which is suitable for closure by palpatory methods, indicated the necessity for dissection studies to locate the atrioventricular node and bundle and to determine whether or not landmarks could be found to enable the surgeon to avoid the structures during external suture closure of the inferior defect

SURGICAL ANATOMY OF THE ATRIOVENTRICULAR CONDUCTION SYSTEM

A series of normal hearts and hearts bearing atrial septal defects were dissected by the technique described by Widran and Lev [4] This series included the heart of a patient who had died during the course of an apparently uncomplicated closure of a defect when a suture had been passed about a major left bundle branch of the conduction system The rapidly deteriorating course of this patient immediately following the onset of nodal rhythm on tying of the suture further indicated the hazard of node injury

In the normal heart (Fig 4), the main atrioventricular node, the main bundle, and all bundle branches lie below a line connecting the Thebesian valve to the central fibrous body in the tricuspid annulus Septal defects of the types in which the orifice lay well above this line (superior and mid-atrial marginal defects) presented a considerable remnant of septum containing no specialized conduction tissue Defects of the types in which the orifice lay along or anterior to this line (inferior, common atrium, and endocardial

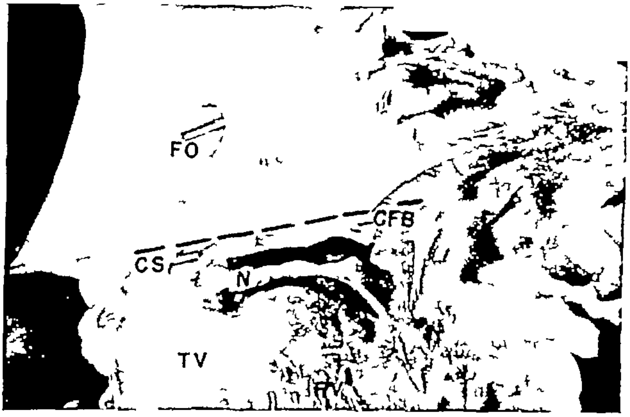

Fig 4 —Dissection study of the atrioventricular conduction system in a normal heart of a newborn infant. The tricuspid valve (*TV*) has been partially excised and the atrio ventricular node (*N*) exposed beneath the right atrial endocardium The main bundle passes to the right from the node to bifurcate into left bundle branches (divided) and the right bundle branch which passes downward to the right ventricle (*RV*) A dotted line passing from the coronary sinus (*CS*) to the central fibrous body (*CFB*) forms a landmark line above which conduction tissue is not found The coronary sinus and central fibrous body may be palpated at the time of operation A probe patent *foramen ovale* (*FO*) is present.

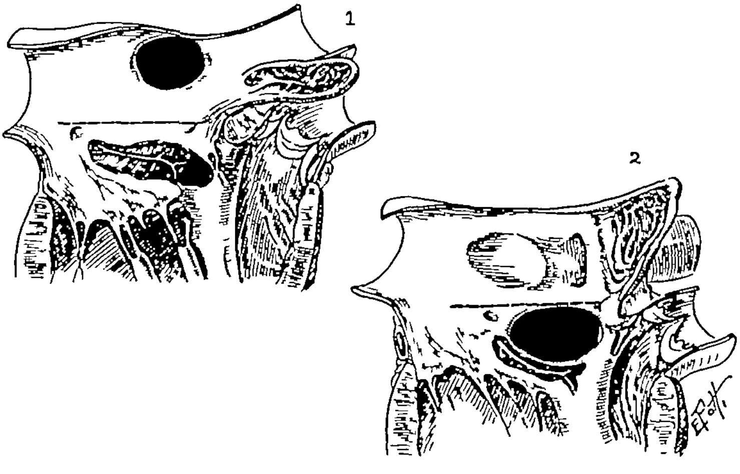

Fig 5 —Dissection study of the atrioventricular conduction system in hearts with atrial septal defects *1*, With a defect of the superior marginal type (Type 5) the conduction system is located well away from the lower margin of the defect. The line connecting the landmarks of the coronary sinus and central fibrous body indicates the most superior limit of any conduction tissue *2* With a defect of the endocardial cushion type (Type 2) the entire orifice of the defect is located below the line In such a defect the atrioventricular node makes up the inferior margin of the orifice.

cushion defects) all had conduction tissue in the anterior edge of the defect Definition of this line by palpation at operation should permit evaluation of the position of the specialized conduction tissue

It was found that both the Thebesian valve and the central fibrous body could be palpated easily by the exploring finger placed in the atrial appendage at the time of defect closure The coronary sinus orifice is located at the anterior edge of the inferior vena caval orifice The Thebesian valve feels like a taut paper-thin ridge over this orifice When the finger is swept upward from the Thebesian valve along the septal segment of the tricuspid valve annulus, it comes to rest naturally in the commissure between the septal cusp and the infundibular cusp of the tricuspid valve At that point the central fibrous body presents on the surface of the tricuspid annulus as a pitted depression 2 to 3 mm. in diameter Location of these two points permits orientation of the position of the conduction system which lies anterior to the line The atrioventricular node and entire bundle are located at the margin of the endocardial cushion type of defect The inferior type of defect, on the other hand, may present only a small segment of rim close to the node and adjacent segment of bundle The remainder of the bundle and its branches will lie anteriorly and superiorly deep in the well-formed superior remnant of atrial septum. The anterior portions of the bundle and branches are more variable in location than the node and adjacent segment of bundle, so persistence of the superior septal remnant greatly simplifies surgical management Definition of the landmarks and connecting line is now used routinely during the exploration of all atrial septal defects

SPECIAL TECHNICAL PROBLEMS IN CLOSURE OF DEFECT BY THE EXTERNAL SUTURE METHOD

Of the five groups of atrial septal defects, the three groups located posteriorly in the septum (inferior mid-atrial marginal and superior marginal) were best suited for closure by the external suture method Since these three groups make up 86 per cent of the defects in our experience the external suture method has been most commonly used Each of the three groups presents special problems in closure

Inferior Defects—In the closure of this type of defect we have made use of the method of defining the position of the atrioventricular node The tricuspid and mitral valve annuli are well formed and create a broad shelf suitable for placement of sutures Once the position of the A-V node is defined sutures can be passed into the left atrial side of the shelf more on the mitral annulus than the tricuspid annulus This avoids the conduction system which lies beneath the endocardium on the right atrial side of the shelf

After extensive mobilization of the left atrium inferior to the right pulmonary veins sutures may be introduced into the left atrium inferiorly near the anterior lip of the defect This maneuver has the advantages of eliminating the possibility of inferior caval obstruction, of placing the least tension on the suture line and of creating a suitable arc for passage of the needle outward after it has traversed the anterior lip of the defect *After placement of* the most inferior sutures in this manner, the succeeding sutures pass more to the right of the right inferior pulmonary vein, thereby creating a suture line which curves upward around the vein Neither the vein nor inferior vena cava is obstructed The steps in this method of repair are shown in Figs 6 and 7

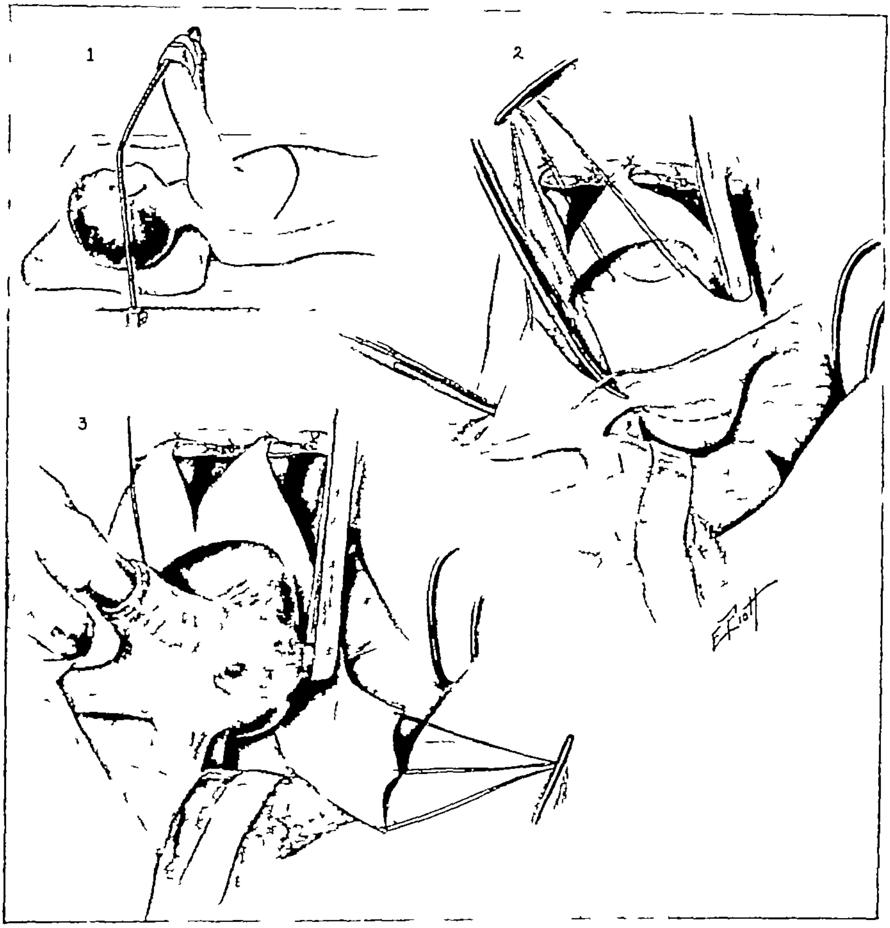

Fig 6 —External suture closure of an atrial septal defect of the inferior type *1* Position of the patient on the operating table *2*, Following exposure of the heart, the auricle is explored through the atrial appendage to evaluate the type of defect present. If a Type 3 defect is present the right phrenic nerve is mobilized and the pulmonary ligament and pericardium are divided posteriorly *3* Retraction of the lung and posterior pericardial flap provides exposure of the posteroinferior aspect of the left atrium near the defect.

Mid-atrial Marginal Defects—The septal remnant anterior to this large defect may be quite attenuated Care must be taken to avoid tearing of sutures In large defects we place all sutures before tying so that all sutures may be tightened to distribute tension evenly A useful instrument has been designed to push the atrial wall downward to meet the septum in those cases where the right atrium is greatly dilated with blood If the other digits of the palpating hand are passed behind the atrial appendage into the groove occupied by the aorta, the atrial septum may be pushed posteriorly, separating it from the ascending aorta and relieving tension as sutures are tied

On many occasions we have made use of the maneuver described by Bailey,[5] of invaginating the lateral right atrial wall into the defect. Defects of the mid-atrial marginal type are suitable for such invagination since they lie at a considerable distance from either caval orifice and the cavae are not compromised by invagination. We have attempted, however, to secure the invaginated right atrial wall to all edges of the defect in order to create a closure which is flush with the septal surface of the left atrium. This avoids the creation of a diverticulum containing suture material and traumatized tissue which might act as a source of emboli to the systemic circulation.

Superior Marginal Defects—These small defects have been the easiest to repair. On occasion it has been useful to mobilize the superior vena cava and

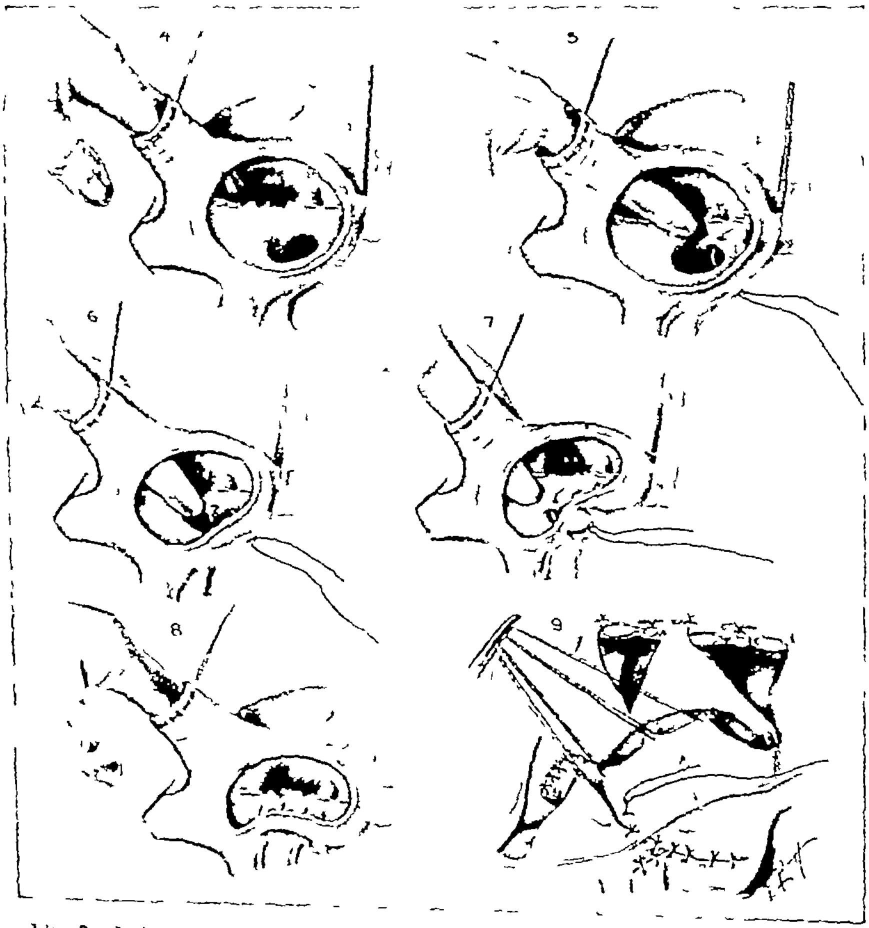

Fig. 7—External suture closure of an atrial septal defect of the inferior type. 4 By palpation the line connecting the coronary sinus and central fibrous body is defined. Atrio ventricular node tissue lies on the right ventricular side of this line. Although the inferior type defect abuts on the valve rings there is a broad shelf of mitral valve ring inferiorly which contains no conduction tissue. 5 The first suture is passed into the *left atrial* wall which lies close to the anterior lip of the defect. 6 The suture passes through the mitral shelf and emerges from the heart through the wall of the right atrium. 7 Successive sutures pass to the right side of the right inferior pulmonary vein. 8 Closure is thus effected by a suture line which curves around the orifice *of the inferior* pulmonary vein. 9 Repair of the pericardial defect and closure of the atrial appendage

retract it upward with an encircling tape so that sutures may be placed toward the left atrial side of the right pulmonary veins in a manner similar to the closure of the inferior type of defect The method of closure is shown in Fig 8

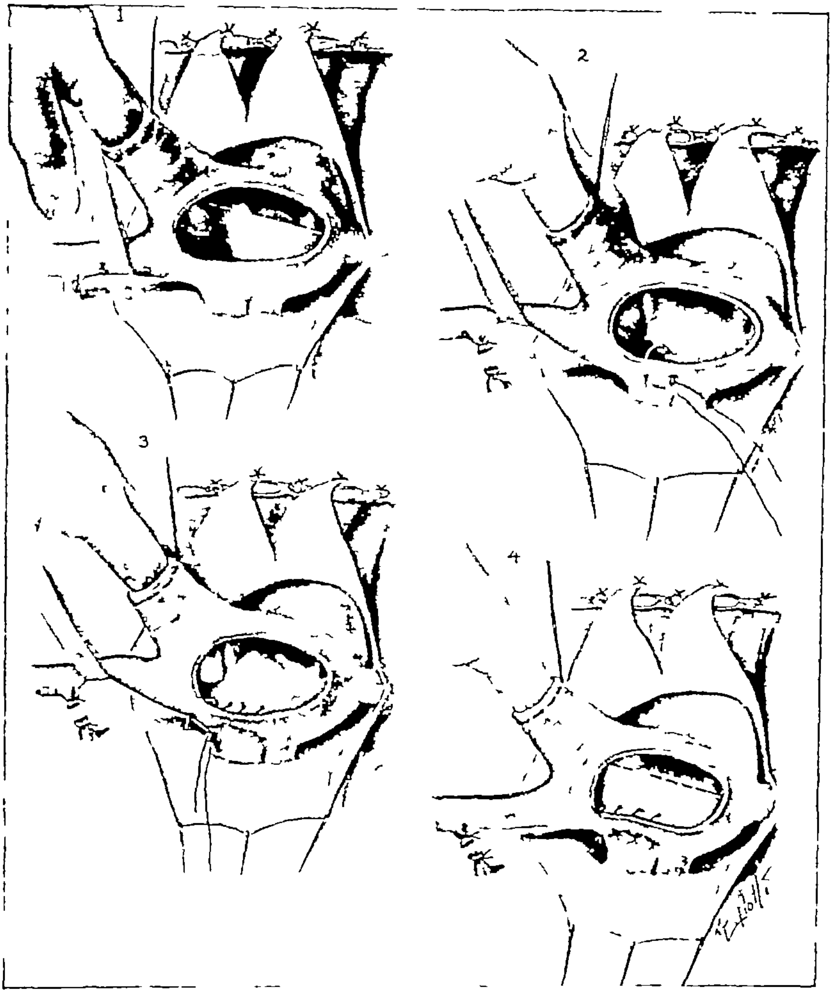

Fig 8 —External suture closure of an atrial septal defect of the superior marginal type *1* The usual pericardial opening is extended by complete mobilization of the superior vena cava from the pericardial reflexion The defect is explored and the position of the atrioventricular node defined A traction tape is placed about the superior vena cava *2* Inferior sutures are placed to the right of the root of the pulmonary vein A finger passed behind the atrial appendage into the aortic groove pushes the septum posteriorly to compress the orifice of the defect and push it away from the ascending aorta which lies behind the right atrium Retraction of the superior vena cava compresses the orifice of the defect and facilitates the placement of sutures *3* Superior sutures are passed into the heart through the left atrial wall to avoid occlusion of the superior caval orifice *4* The defect is closed by a suture line which curves about the orifice of the superior pulmonary vein

ANOMALOUS PULMONARY VENOUS DRAINAGE WITH ECCENTRIC DEFECT

Since anomalous drainage of the right pulmonary veins into the right atrium has been associated exclusively in our experience with inferior or superior marginal defects, the veins have drained into the atrium some distance inferior or superior to the orifice of the defect We have found it useful to insert a small tonsillectomy knife through a purse-string suture in the wall of the right atrium Under control of the palpating finger, this knife is used to enlarge the atrial defect upward or downward so that the enlarged orifice may be sutured to the right of the transposed veins This maneuver corrects the anomalous venous drainage and obliterates the interatrial communication at the same time It is useful to define the landmarks of the conduction system in planning the location of this incision so that the enlarged defect and following sutures can be located away from the node

POSTOPERATIVE MANAGEMENT

Patients have presented few special problems in postoperative care Each patient receives quinidine An indwelling catheter is used to measure urinary output accurately at hourly intervals The measurement is useful during the first few postoperative days in determining whether or not the patient is retaining fluid. If this is the case, it may be anticipated that the patient will develop a peculiar syndrome of transient left ventricular failure The failure is presaged by the retention of fluid and gain of weight during the first few days after operation Between three and fourteen days after operation, such patients have complained of pain and tenderness in the right upper quadrant Definite signs of hepatic enlargement then appear X-ray studies at that time have shown pronounced enlargement of the left atrium and progression of the pulmonary congestion which was present before operation.

The syndrome must be recognized promptly since it is accompanied by electrolyte derangements and hemodilution due to retention of fluid The falling hematocrit must not be interpreted as an indication for blood transfusion Transfusions will increase the blood volume further and aggravate the condition Plasma volume studies indicate the true picture—a constant red cell mass and rising plasma volume with resultant reduction of peripheral hematocrit

Arrythmias are frequent during this period The most common disturbance is auricular flutter Conventional methods of medical therapy have been employed but the most valuable therapy in management of the arrhythmia has been directed toward control of the underlying congestive failure The arrythmias tend to disappear spontaneously once compensation is achieved

Our difficulties became less frequent once we began to shape our immediate postoperative care in anticipation of a period of transient failure Fluid intake has been limited in all patients The afebrile adult receives a maximum of 1 500 c c per day Sodium intake has been restricted. Blood replacement has been gauged by loss measured at operation and through thoracotomy tubes We have used *mercurial* diuretics without complications We have not restricted the use of blood transfusion during operation or during the immediate postoperative period, but have routinely given 20 to 50 c c of 50 per cent glucose intravenously immediately after operation We have frequently observed mild hypotension during the immediate recovery period

When this is unaccompanied by oliguria and signs of peripheral vascular collapse, we are not very much concerned, but serious hypotension accompanied by oliguria has been treated by transfusion. Digitalis has been given if signs of congestive failure are seen. When the requirements for blood replacement appear greatly in excess of operative blood loss and chest tube drainage, vasopressors have been valuable adjuncts to transfusion.

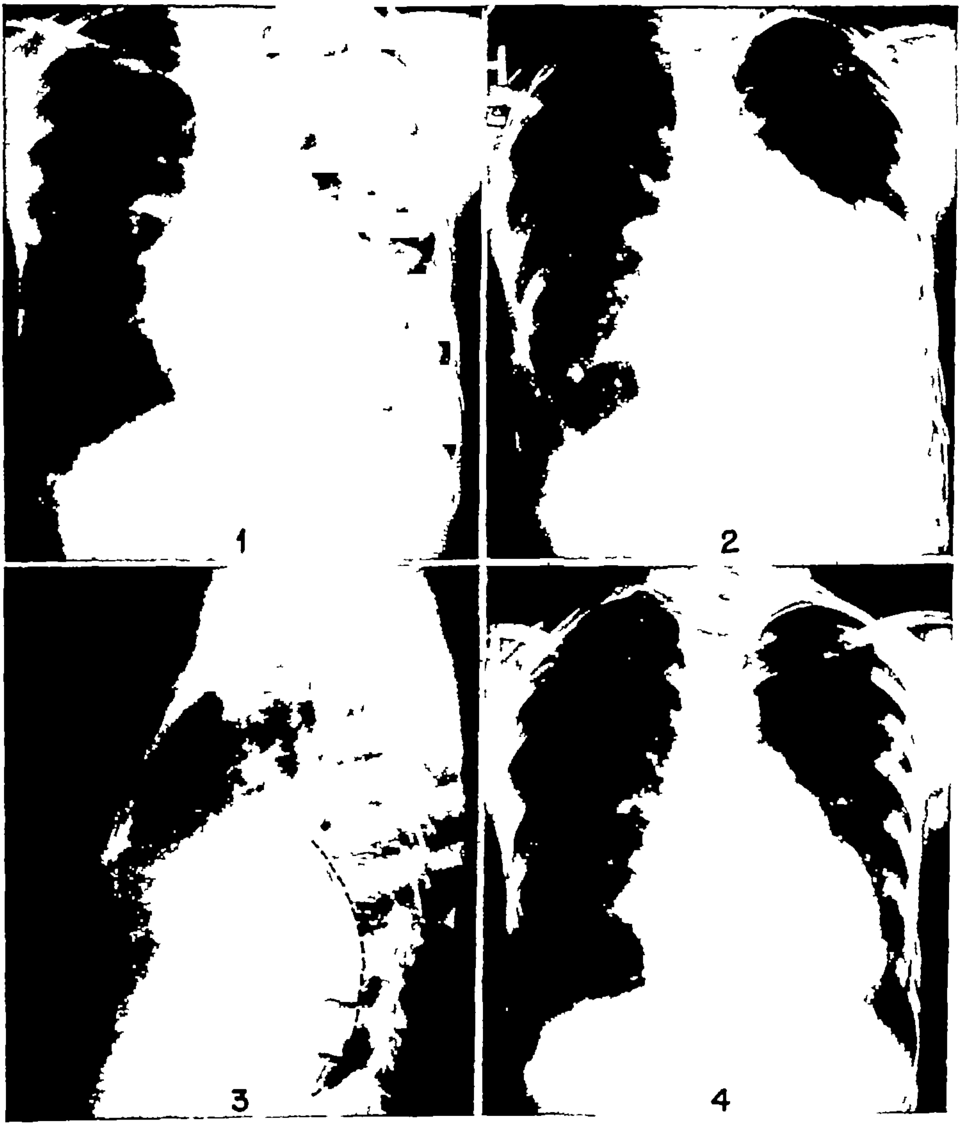

Fig. 9.—Chest x-rays of a child showing transient left ventricular failure after atrial septal defect closure. *1*, Preoperative film. The heart is enlarged and there is pulmonary congestion. *2*, Nine days after closure of a large defect. There is failure of the left ventricle with a large heart and increased pulmonary congestion. *3*, Left lateral view showing left atrial enlargement. *4*, Seven weeks after operation there is decrease in right atrial size and decreased pulmonary congestion.

Studies by our associates suggest that the transient left ventricular failure may be related to the altered conditions under which the left ventricle is functioning after operative closure of the atrial defect[6] Preoperative studies indicate that an atrial septal defect impairs filling of the left ventricle by acting as a vent through which blood is shunted to the low-pressure venous system Since the left side of the heart is unable to maintain an adequate diastolic filling pressure, left ventricular stroke output is diminished and the

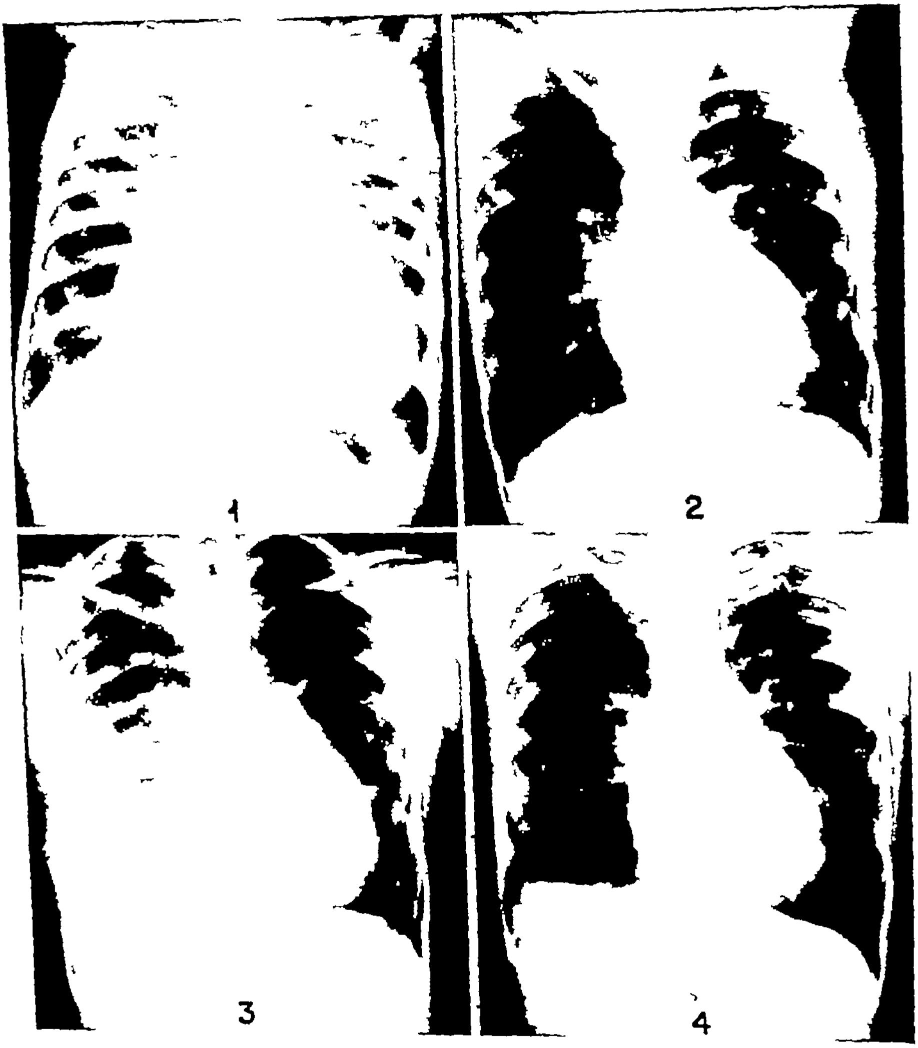

Fig 10—Chest x rays of children with atrial septal defects and after operative repair *1* A 4 year-old child presented serious symptoms and great cardiac enlargement with only a small shunt flow (1 5 1 ratio of pulmonary flow to systemic flow) This combination of findings suggests that the course will be poor The patient died of congestive failure after operation *2* In contrast, a 7 year-old girl presented enormous shunting (4 1 ratio of pulmonary flow to systemic flow) with only minimal signs of cardiac enlargement and pulmonary congestion This combination of findings suggests a benign course *3* Four days after operation there is no evidence of left ventricular failure. The course was uncomplicated *4* Seven months after operation the heart is small and the lung fields uncongested

ventricle remains small at all times It seems logical to assume that the diminution of left ventricular volume over the period of years prior to closure of the defect would impair the growth of the left ventricle and impose an unaccustomed burden upon it immediately after the defect is closed at operation We have had occasion to see several autopsy specimens in which the left ventricle was diminutive in the presence of a large septal defect The mitral valve was hypoplastic and a pathologic diagnosis of "mitral stenosis" had been rendered although the valvular deformity was obviously not of rheumatic origin

Postoperative Embolization—Disconcerting neurological changes have been seen in 3 patients Presumably thrombotic emboli had broken away from the left atrial surface of the defect repair In 2 patients, transient minor changes were gradually resolved In an 8-year-old girl, coma and decerebrate changes occurred suddenly twenty-four hours after an uncomplicated external suture repair of a mid-atrial marginal defect closed by a U-shaped suture line This closure may have left an appreciable diverticulum of excluded right atrial chamber in communication with the left atrium Death followed the development of serious electrolyte disturbances Autopsy could not be obtained

We can prove no definite cause for embolization, but believe that minimization of tissue trauma and avoidance of appreciable depressions in the left atrial surface of the defect closure will reduce the incidence of such complications Pulmonary embolization has not been seen

RESULTS OF OPERATION

We have performed exploratory operations on 46 patients with a preoperative diagnosis of atrial septal defect In 3 patients, the diagnosis of atrial spetal defect was in error despite clear-cut signs and adequate preoperative catheterization studies The common cause of this error was a ventricular septal defect with tricuspid regurgitation which could not be differentiated from an uncomplicated atrial septal defect by preoperative studies

The remaining 43 patients had an atrial septal defect In the first consecutive group of 22 patients, there were 9 deaths Six of the deaths were due to technical errors which have proved avoidable with increasing experience In the last 21 patients, there have been 4 deaths Two deaths followed attempted closure of endocardial cushion defects with pronounced valvular deformity Two deaths were due to immediate congestive heart failure following uncomplicated closure of mid atrial marginal defects with advanced pulmonary vascular obstruction None of the procedures were complicated by avoidable technical errors Consequently, we now regard defects with associated anatomic valve deformity or with advanced pulmonary vascular obstruction as not amenable to repair by our present methods

The diagnosis of true pulmonary vascular obstruction can be made by adequate preoperative catheterization studies True pulmonary vascular obstruction must be differentiated from the common innocuous pulmonary hypertension due to tremendous flow through a normal pulmonary vascular bed

Differentiation can be made only by calculation of pulmonary arteriolar resistance or some similar index based upon the ratio of pulmonary mean arterial pressure to pulmonary blood flow. Normal values for these indices have been published.

We do not know of any way short of digital exploration of the atrium to diagnose the endocardial cushion type of defect with valve deformity. Its presence may be suspected in the patient who presents lower sternal thrills and harsh systolic murmurs in the absence of catheterization evidence of an associated ventricular septal defect.

We have not performed postoperative cardiac catheterization studies during the time of the hospitalization for operation because we believe that the patients should be restored to full activity prior to evaluation of the results of operation. In one patient this policy has been supported by the reappearance of a systolic pulmonic murmur some time after discharge suggesting reopening of a small shunt. A small shunt was present at the time of late postoperative catheterization.

Nine patients have been catheterized. Six children have been studied. Complete closure of the defect has been demonstrated in four. In 2 of our earlier cases, there is evidence of persistence of a greatly diminished shunt. It is also encouraging to see a pronounced difference between right atrial pressure and left atrial pressure after operation in all patients with closed defects. The rise of left atrial pressure ("pulmonary capillary" pressure) with the reduction of heart size and pulmonary congestion indicates that closure of a defect allows the left atrium to fill more effectively under a higher pressure. We hope that this will allow the left ventricle to fill more efficiently and to develop normally after operation.

The success of closure of defects in the adults cannot be evaluated from our present data because we have selected chiefly those patients suspected of residual shunting for early catheterization. Of 4 such patients, the shunts have been only slightly reduced in 2, reduced to one-third in one, and completely obliterated in one. The last patient has shown a rise of 9 mm. in pulmonary capillary pressure.

Clinical improvement has been striking. All patients have reported an increased exercise tolerance and relief of symptoms. Many of the younger patients with large shunts were reported as asymptomatic prior to operation but the degree of their incapacity became obvious to the parents only after surgical repair allowed the children to compete efficiently with their schoolmates at play. Convalescence in the adult patients has been slower than in the children.

The characteristic murmurs of atrial septal defect have altered after operation but persistence of some type of pulmonic murmur has been seen in several children whose defects have been proved to be repaired by catheterization. The murmur may be related to anatomic deformity of the large pulmonary vessels since it tends to diminish gradually with growth of the patient. The persistence of apical diastolic murmurs has been a more reliable sign indicating the persistence of appreciable shunts after operation This type of murmur has disappeared in patients in whom complete closure of the defect has been accomplished

SUMMARY

1 Surgical repair of atrial septal defects has proved to be a useful procedure in our hands

2 Arbitrary indications for operation were selected early in our experience to include only those patients with considerable evidence of disability or impending difficulty from large shunts The indications we have used are (a) persistence of incapacitating symptoms despite optimal medical management, (b) persistence of serious cardiac enlargement and pulmonary congestion, or, (c) catheterization evidence that right ventricular output was more than twice left ventricular output

3 The common location of defects along the posterior margin of the atrial septum has made it possible to utilize external suture methods exclusively during management of our last thirty patients The atrial well method is more versatile but is not necessary for the repair of most defects

4 A classification is made of the surgical anatomy of forty three defects observed at operation This classification has been made with the intention of differentiating those low-lying defects associated with atrioventricular valve deformity from defects without valve deformity lying near the inferior vena cava Serious regurgitation with the former type of defect has been aggravated by surgical repair The latter type of defect is amenable to surgical repair but presents technical difficulties in the danger of injury to specialized conduction tissue in the atrioventricular node and bundle This tissue may be located by palpation of two landmarks within the atrial chamber—the valve of the coronary sinus and the central fibrous body Conduction tissue is not found posterior to a line connecting these two landmarks

5 When a defect lies near a caval orifice, it is useful to employ sutures introduced into the heart through the left atrial wall This avoids constriction of the caval orifices by suture

6 Postoperative management of patients has been complicated on occasion by the appearance of transitory left ventricular failure All patients are placed on a prophylactic regime of fluid limitation during the immediate postoperative period. Digitalis and mercurial diuretics are given if failure develops Arrythmias have been common in patients during this period of failure

7 Catheterization evidence of the success of closure of the defect is not complete Evidence of a rise of "pulmonary capillary" pressure after success ful closure of the defect indicates that operation improves the diastolic filling of the left ventricle

8 During our last twenty-one consecutive cases, deaths have occurred only in the presence of advanced disease—advanced pulmonary vascular

obstruction in two patients and serious atrioventricular valve deformity in two patients We now regard these conditions as contraindications to defect closure by our methods

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DISCUSSION

DR CHARLES P BAILEY, Philadelphia, Pa —There is really not much to be added to this presentation of Dr Gross and Dr Watkins We performed the first atrioseptopexy operation in 1952, in February, and since that time have operated on 73 more patients, on whom this technique or some modification was used Among them were 57 with so-called septum secundum defects There were 5 deaths in that group With 3 exceptions those who have been recatheterized—about two thirds of the entire series— have been proved to have complete closure of the defect We operated on 17 primum defects and we have a mortality there that I am ashamed of—more than 60 per cent Therefore, we have stopped operating on septum primum cases We have used the supine position rather than the lateral position which Dr Gross has used, and have found it quite satisfactory Six of these patients presented coexisting mitral stenosis and this lesion was relieved at the same time, 3 of these lesions were found inadvertently during the performance of mitral commissurotomy from the right side This approach, of course, makes it convenient to repair the defect at the same time In 16 cases there was anomalous pulmonary venous drainage, in all but 2 to the right lung One of these was limited to the left side and we did not do anything about it The other was a patient with complete anomalous venous drainage, whom we operated on in two different stages One patient had anomalous right venous drainage and no septal defect You saw the method Dr Gross used for diverting the anomalous right pulmonary venous drainage into the left atrium, and of course we used practically the same method But in this instance there was no septal defect After due consideration we created a posterior septal defect and then sewed the right atrial wall to the anterior margin of the created defect, and in that fashion we rerouted the venous blood from the right lung into the left atrium

I cannot congratulate Dr Gross enough for his efforts to demonstrate exactly where the common conduction bundle lies That is a very important landmark Up to now we have been guided solely by the location of the coronary sinus ostium and have tried to keep our suture line above the valve Unfortunately, in 4 of our 16 primum cases we did interrupt the conduction bundle Since 3 of these 4 patients died, we thought it was a most serious accident in contrast to certain other more favorable reports of recovery after surgical division of the conduction system

We always mobilize the atrial wall if it does not seem large enough for our purposes by the method Bahnson has suggested, that is, a separation of the interatrial groove If one puts a finger in the right atrium so that one does not separate the groove all the way up to the defect, the additional separation is not hazardous When sufficient atrial wall has been mobilized, one can readily repair, I find, even a defect which is more common with us than the posterior one just described, that is, one just behind the aorta running up as high as the superior vena cava There is a posterior septal margin, but none anteriorly Perhaps we see this anterior defect more commonly because most of our patients are adults

DR DENTON A. COOLEY, Houston, Texas —The excellent results presented by Drs Watkins and Gross using mostly closed methods of repair of atrial septal defects are very impressive I too am convinced that a large number of such anomalies can be corrected without resorting to temporary interruption of the circulation Some problems in cardiac surgery inevitably will be solved by technical improvements alone It is true that open heart surgery is developing rapidly with its many obvious advantages On the other hand there is a certain inherent risk involved in temporary by pass of the heart, and this may be especially important in patients with severe cardiac embarrassment Such risks could be avoided by use of a simplified method based largely upon anatomic features of atrial defects which facilitate their repair

Although my experience with surgical closure of interatrial septal defects is comparatively small, the results have been encouraging In my opinion the modifications devised by several Scandinavian authors of Dr Gordon Murray's technique of septal suturing provides the simplest and most effective method of dealing with septum secundum and some ostium primum defects An advantage of the purse string suture is that it will close multiple defects when they exist Addition of a couple of mattress sutures through the septum reinforces the closure and prevents the purse string suture from pulling through the atrial wall

I have tried a similar technique of suturing for ventricular septal defects in which mattress sutures are passed through the ventricular septum This method was tried in 3 patients and one died from hemorrhage twenty four hours later when the mattress suture pulled through the myocardium In the 2 surviving patients there were no complications and the defects appear to be reduced significantly in size Although these results are not as impressive as some reported by Lillehei where cross circulation was used, it may be that the procedure will have some usefulness in infants and small children One should be ready to combine the best features of all methods which have been proposed, if necessary, in the development of an ideal operative technique

DR CONRAD LAM, Detroit, Mich —I should like to present a modification of the technique of atrioseptopexy This method embodies some of the features of the methods used by Dr Bailey and by Dr Gross

(Slide) This autopsy specimen illustrates the anatomy of interatrial septal defect One notes the large defect, the tricuspid valve, and the orifices of the venae cavae If the posterior rim of the defect is pushed anteriorly, the defect is closed If it is maintained in this position by sutures, a satisfactory repair has been obtained These sutures can be placed by a closed technique, with the use of a two pointed needle with the silk swaged on in the middle

(Slide) We first carry out the Sondergaard dissection, separating the pulmonary veins from the right auricle This permits the needle to be inserted either through the posterior rim or just to the left of it The needle then passes through the anterior rim of the defect, and the point emerges from the auricular wall at any convenient place It is grasped with the needle holder and when the trailing point has cleared the anterior rim, the direction of the needle is changed so that the trailing point emerges from the auricle near where the needle first entered

(Slide) As many sutures as necessary are placed to close the defect completely There is no danger of interfering with vena caval flow or the conduction mechanism

We have closed 13 defects of the septum secundum type by the closed method, without a death We encountered 4 of the so called ostium primum type These could not be closed by the external method and 2 patients succumbed after exploration

The two pointed needle is similar in design to that which Dr R A Cowley has used for blood vessel anastomosis

DR HENRY T BAHNSON, Baltimore, Md —We have encountered a fair number of anomalies of the venous return in extremely ill pediatric patients with auricular septal defects Most present no problem as they can be closed by shifting the septum as Gross and others have described.

(Slide) In patients such as the one shown here the problem is a different one This patient had a total anomaly of the pulmonary venous return, all the veins draining into an additional atrial chamber We debated quite a while trying to decide what to do, and ultimately came up with an idea that may be helpful to some of you We had previously dissected in the groove between the atrium and the pulmonary veins, with the technique Dr Bailey ascribed to me but which goes back to Sondergaard as others have mentioned. This is very helpful in anomalous venous return because if one dissects in this groove he cannot miss the anomalous drainage We simply began with a purse string suture adjacent to the aorta as Crafoord and Bjork have described, continued this on around and took bites on the anterior wall of the right atrium, the right atrium in this condition is large and quite roomy This is tied down, and as you see we have converted a heart with three atria into one with four atria We have made the inferior vena cava and the coronary sinus vein drain through the tricuspid valve The pulmonary venous drainage which came into the third atrium went through a septal defect to the remaining right and thence to the left atrium In essence this left the superior cava draining with the pulmonary veins to the left heart, so we tied down the superior cava between the azygos vein and the right auricle over a nerve hook to obstruct this flow and direct it through collaterals to the inferior cava We later wrapped this with a piece of cellophane We were quite gratified to find that when the pressures were measured—we measured pressures prior to placing the suture, and following—the pressures in the pulmonary vein, the original right atrium, our new right atrium, and the third atrium, all had fallen from the preoperative values The pressure in the superior vena cava, the drainage of which was partly constricted, was similar to that which had been recorded before the procedure The patient made an essentially normal recovery except that we noticed for the first few days he did not like to lie flat, a common symptom of the superior caval syndrome At the time of his discharge he was lying flat

This is the condition which I think is present in many patients with total anomalous pulmonary venous return The procedure is almost certainly equally applicable to the total anomalous venous return in which all the veins empty into an anomalous left superior cava, the so called "snow man mediastinum" which is seen on the roentgenogram

DR F J LEWIS, Minneapolis, Minn —I would like to congratulate Dr Watkins and Dr Gross on their presentation of pioneer work in this field I would like, also, to express my admiration of the ingenious methods which the other discussers have used to close atrial septal defects without looking at them Finally, I want to advocate an open method for repairing these defects

Most of us have been trained in a method of eye hand coordination by which we do most surgery, and I think we would do best to repair atrial septal defects the same way, employing our vision as long as it remains acute

(Slide) This shows cases we have operated on to repair atrial septal defects during the past two and one half years As you can see, the open technique leads to a slightly lower mortality rate (4 deaths in 33 cases) but it also has other advantages We are able to identify the complex anatomy typical of some of these defects and place the stitches precisely where they should be placed

These cases are divided into groups according to a classification we have used It is based on their embryological development as well as their appearance when we see them in the living heart We will explain the classification in detail in a presentation during the latter part of the week in Philadelphia The commonest type is the foramen ovale defect which may have associated anomalous pulmonary venous drainage

High defects are particularly interesting I think that some of the defects Dr Watkins showed in his second or third slide are probably high defects, but they cannot be identified with the finger The crucial point in their identification is the presence of a separate foramen ovale below the defect which usually remains closed High defects are a distinct group The low defect (the persistent ostium primum is one type of low defect) is fortunately a relatively rare defect It cannot always be distinguished from a foramen ovale defect by the finger, and I say this from personal experience because we feel all these defects with the finger before we take the trouble to look at them As has been the case with other people doing this work, our worst experience has been with these persistent ostium primum defects because of postoperative complete heart block. When we learned a little more about repairing them in the third case, we employed the lower part of the left atrial wall, which can be pulled back and used to avoid the conduction system, and in that patient complete heart block did not develop until one month postoperatively This adds another possible complication, for in these more difficult repairs late scarring may cause damage

DR EDGAR DAVIS, Washington, D C—I rise not to discuss this but to ask a question. It seems to me that the surgeons operating upon these defects agree that the ostium primum type of interatrial septal defect cannot be satisfactorily closed and concede that they would not operate if the diagnosis could be established clinically I think we would all welcome some discussion of the possibilities of distinguishing preoperatively between the ostium primum and ostium secundum atrial septal defects

DR EARLE B KAY, Cleveland, Ohio—From the foregoing discussion it can be concluded that atrial septal defects can be adequately and safely closed by either open or closed techniques We have preferred the closed technique for we feel that there is less inherent risk to the patient We have operated upon 19 patients by the closed technique with but one death This patient was the second one upon whom operation was performed This patient was 41 years of age and had markedly elevated pulmonary artery and right ventricular pressures associated with arterial desaturation (84 per cent) According to our present standards, she was beyond hope of surgical benefit and should not have been operated upon

I would like to stress that after pulmonary hypertension and arterial desaturation of significant degree occur, operative closure of atrial septal defects is contraindicated

DR WATKINS (Closing)—I want to thank all the discussers I am very much impressed by their results It is impossible to discuss all the points raised here, but certain facts should be emphasized

First, the indications for surgical repair of atrial septal defects are apparently varying in different medical centers The particular patients upon whom we have performed exploratory operations have either had tremendous flows through their defects or have had debilitating symptoms Second, we surgeons at present are talking loosely about "pulmonary hypertension" Every patient with a large volume of blood flow through an atrial septal defect will have pulmonary hypertension simply because enormous volumes of blood are being forced through a normal pulmonary vasculature This innocuous condition must be differentiated from true pulmonary vascular disease, in which there is also a high pulmonary artery pressure but a low flow The only way one can differentiate these two conditions is by a measurement of pulmonary blood flow and pulmonary arteriolar resistance at cardiac catheterization The physiologists tell us that systemic and shunt flow measurements are not valid, because one cannot possibly get a true mixed venous blood sample in the presence of an atrial septal defect, so we neglect all flow observations However, a Fick systemic flow calculation based upon the superior vena caval oxygen content is a useful rough clinical estimate of left ventricular output, and the more accurate pulmonary flow measurement permits calculation of pulmonary arteriolar resistance Such observations are necessary to differentiate the common benign condition of pulmonary hypertension due to large blood flow from true pulmonary vascular disease

We have had no experience with the methods of Sondergaard, Bjork, and Crafoord However, we have had some difficulty with sutures which pass near the aortic root The clearances between the coronary artery ostia at that point are rather close, and I am going to try to find out how I can avoid them, from people who have had more experience with the method Moreover, defects which lie near the point of branching of the conduction system will present conduction tissue on either side of the septum Sutures passed to the left of the major conduction system near the anterior edge of the tricuspid annulus can quite easily traumatize the major left bundle branches I would be interested in knowing how one can avoid these structures

I believe that Dr Bahnson's procedure is the solution of an entirely different problem We have had some experience with diversion of complete pulmonary venous transposition by a somewhat different technique It seems to us that the major problem in any procedure for this condition stems from the fact that the left ventricle and left atrium are very hypoplastic because of the complete diversion of the venous stream Consequently, a word of caution might be raised here about the train of events following sudden surgical diversion of all pulmonary venous drainage into such a hypoplastic left atrium and left ventricle

We have not used hypothermia We believe that methods for external suturing are quicker and easier for the majority of atrial septal defects although it may take a longer time to describe the actual technique of suture placement

In reply to Dr Davis' question about the differential diagnosis of the *ostium primum* defect, we know of no way to diagnose such a lesion definitely, although we are suspicious when there are harsh systolic murmurs along either lower sternal border In a number of our patients who have had such murmurs, we have found either low lying defects of the endocardial cushion type or ventricular septal defects with tricuspid regurgitation Several of our patients who have had complete closure of the defect have had persistence of pulmonary systolic murmurs The most reliable criterion we have had of complete closure is disappearance of apical diastolic murmurs

LEFT-SIDED BRONCHOTRACHEAL ANASTOMOSIS

VIKING OLOV BJORK, M.D.
STOCKHOLM, SWEDEN

IN most cases of bronchial stenosis of tuberculous origin the corresponding lung parenchyma is destroyed. Then both the lung tissue and its stenotic bronchus have to be resected.

In some cases of stenosis in the main bronchus, one lobe may be found without tuberculous changes. In order to save this healthy lung parenchyma behind the diseased bronchus, Gebauer,[3] in 1949, introduced a method for reconstruction of the tuberculous stenotic bronchus with dermal grafts. In spite of the encouraging results obtained by Gebauer and others,[3, 4, 5, 7] I have never had the courage to suture a dermal graft into a bronchus with a tuberculous stenosis. The main objection is the possibility of reactivation of the bronchial tuberculosis resulting in serious complications.

On the right side, it is questionable if a plastic reconstruction of the main bronchus with dermal graft is ever indicated. The resection of diseased parenchyma and bronchus with a bronchotracheal anastomosis is a more sound surgical procedure.[2, 5, 6, 7]

On the left side, on the other hand, the technical difficulties in performing a bronchotracheal anastomosis have made the dermal graft reconstruction justifiable.[5, 7]

My earlier attempts to do a bronchotracheal anastomosis on the left side have resulted in pneumonectomies. In 1954, Gravel[6] described an end to end bronchial anastomosis 1 cm. distal to the carina on the left side. Unfortunately, the patient died four months later due to rupture of an aneurysm of the aortic arch. An inflammatory process had caused destruction of the elastic medial layer of the aorta.

The purpose of this paper is to show that with wide mobilization of the aorta after division of the four upper pairs of intercostal arteries, mobilization of the left subclavian artery, esophagus, trachea, and the central part of the right main bronchus, a direct anastomosis of the left lower lobe bronchus to the trachea is a possible surgical procedure. As a resection of the diseased bronchus with direct anastomosis is to be preferred to a plastic reconstruction with dermal graft, hardly any indication for the use of dermal grafts remains in cases of tuberculous bronchial stenosis.

CASE REPORT

A 32-year-old woman had a tuberculous infiltration in the left upper lobe in 1949. There was progress in 1951, and in 1953 a cavity was visible in the

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From Sabbatsberg Hospital. Surgeon-in-Chief: C. Crafoord, M.D., Professor.
Received for publication Feb. 21, 1955.

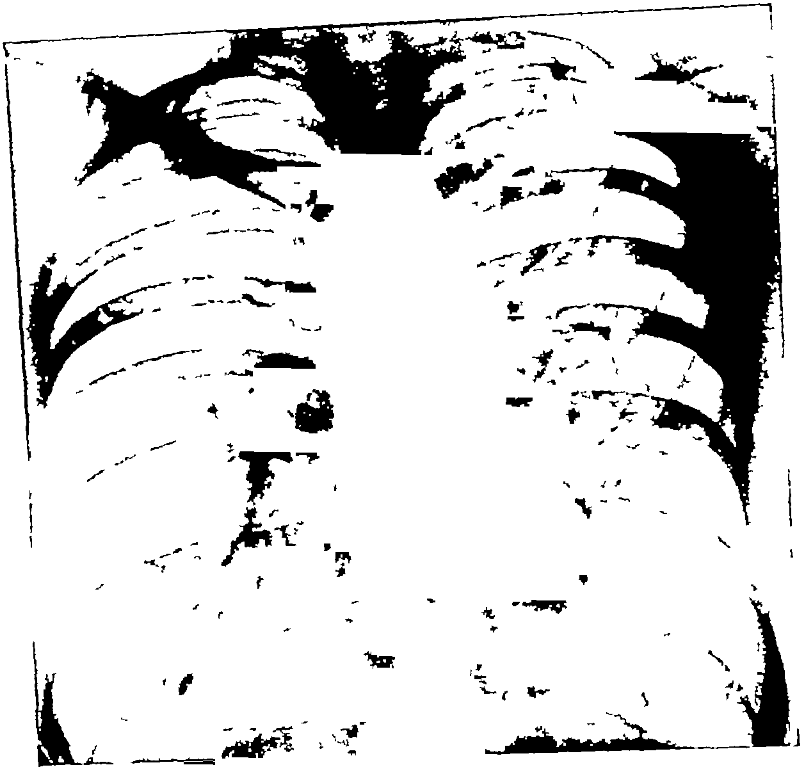

Fig 1—X-ray of the lungs demonstrating infiltrations into the left upper lobe

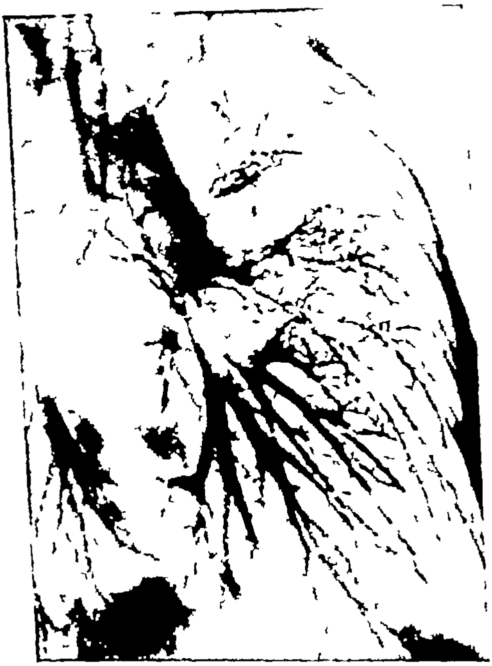

Fig 2—Bronchographs before operation which shows a considerable narrowing of the left main bronchus from the carina down to the left upper lobe bronchus There is no bronchiectasis in the left lower lobe.

left upper lobe She had a very intense irritating cough Bronchoscopy performed in January, 1954, showed a circular ulceration in the opening to the left main bronchus which had only a 3 mm diameter Later bronchoscopy showed the carina involved in the process Bronchography showed a considerable narrowing of the left main bronchus from the carina down to the left upper lobe bronchus The lower lobe bronchus was normal (Figs 1 and 2)

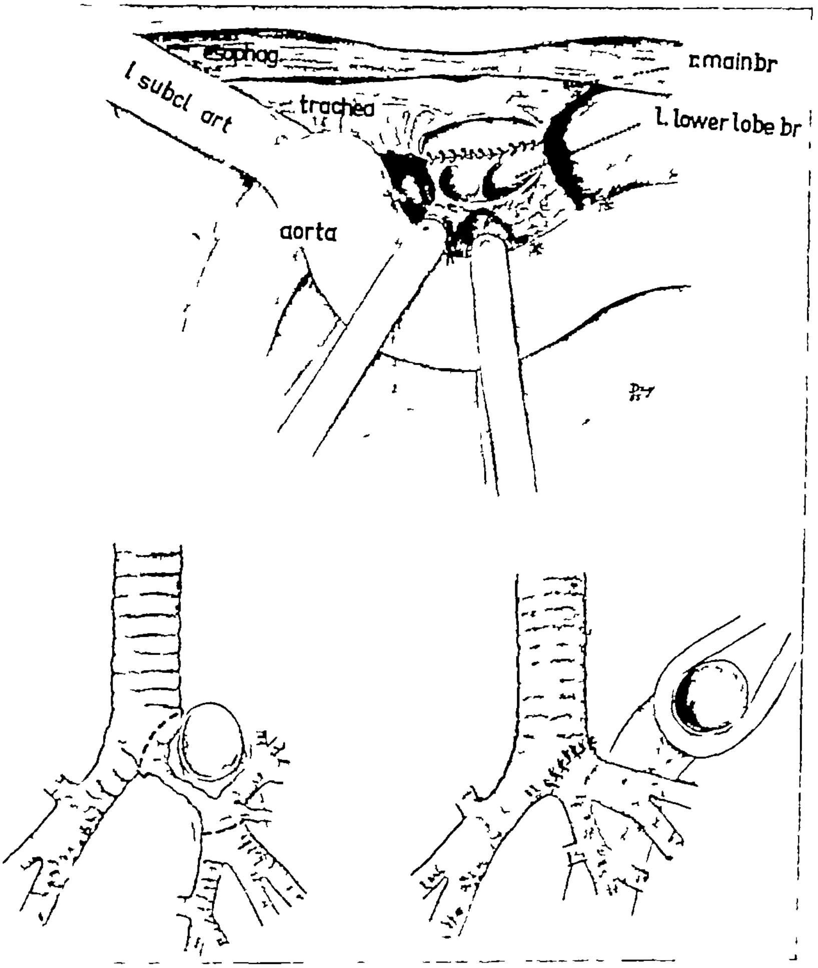

Fig 3 —Diagram of the operation with mobilization of the aorta and direct anastomosis between *left lower lobe and trachea*

At operation (Nov 17, 1954), the patient was placed in the prone position A subcostal incision was made under the fifth rib on the left side Ribs 2 to 6 were divided at the level of the transverse processes The lung was freed intrapleurally and the upper lobe resected The pulmonary artery had to be freed from the left main bronchus by sharp dissection from its origin in the main pulmonary artery to its divisions in the basal segmental arteries The left main bronchus was dissected as far as possible under the arch of the aorta Then the four upper pairs of intercostal arteries were divided and the aorta as well as the left subclavian artery was mobilized forward (Fig 3) The esophagus the left main bronchus, 5 cm of the trachea, and the proximal part of the right main bronchus were dissected free

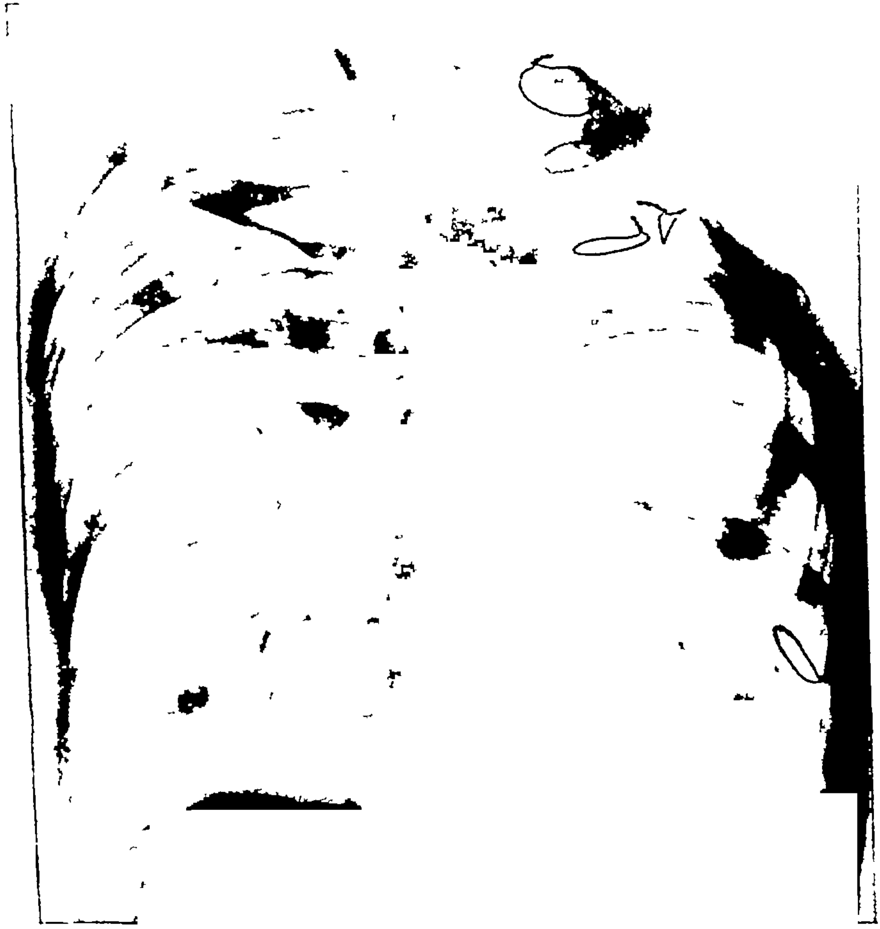

Fig 4 —X ray of the lungs 3 months after operation

The left main bronchus was opened longitudinally in the posterior part It was impossible to judge by inspection only, if there was active tuberculosis in the bronchial wall Now the inferior pulmonary vein was freed but the pulmonary ligament was not divided The left main bronchus was excised from the trachea and divided just centrally to the bronchus to the superior segment of the lower lobe The endotracheal tube was pushed down in the right main bronchus and an airtight connection to the right lung was obtained A Potts' clamp was applied on the lower lobe bronchus which under considerable traction was approximated to the trachea First a row of iso

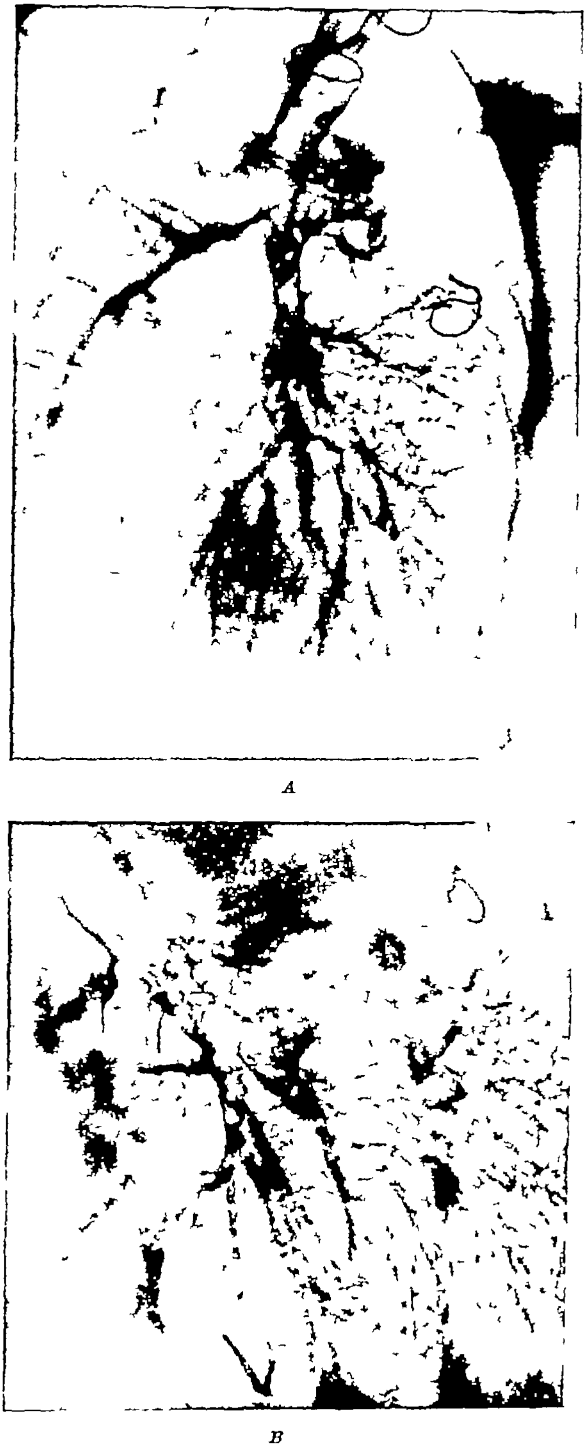

Fig 5 *A* and *B*—A bronchography 3 months after operation which shows a patent anastomosis between the left lower lobe and the trachea. *The opening to the superior segmental bronchus* in the upper angle of the anastomosis to the trachea is also visible There is no bronchiectasis

lated over and over No 00 silk sutures on Atraumatic needles was placed and tied anteriorly It is better to tie these sutures one at a time as soon as they are placed The posterior row of isolated silk sutures was easy to place and tie The bronchus to the superior segment lower lobe was sutured into the superior corner of the incision in the trachea The suture line was not covered with a pleural flap Streptomycin was placed around the suture and the mediastinal pleura closed The pleura was drained and a small osteoplastic thoracoplasty performed.[1] Bronchoscopy after the operation showed the anastomosis open for the 9 mm bronchoscope The patient made an uneventful recovery The remaining left lower lobe was well aerated during the whole postoperative period and there was no need for a bronchoscopic aspiration

Three months after the operation the left lower lobe was well aerated (Fig 4) and bronchography demonstrated a patent bronchotracheal anastomosis There was no bronchiectasis (Fig 5 *A* and *B*) Bronchoscopy had to be performed four times for removal of the silk sutures causing granulomas After removal of the sutures a well-healed anastomosis was seen seven months after the operation

Therefore in a second case of left-sided bronchotracheal anastomosis treated in an identical way and in 3 other cases where the bronchus to the left lower lobe or to the basal segments of left lower lobe was anastomosed to the left-main bronchus 1 to 2 cm below the carina without mobilization of the aortic arch chromic 2-0 and 3-0 catgut was utilized as suture material Bronchoscopic control of these anastomoses performed with catgut showed a smooth healing without granulomas

DISCUSSION

As it is possible to perform a direct anastomosis between the left lower lobe bronchus and the trachea there will not be many cases left for a plastic repair with dermal graft Excision of the diseased bronchus and end-to-end anastomosis will always be preferred when possible

The prone position as advocated by Gebauer for these cases will facilitate the operation The most difficult part is the anastomosis This can be done only after a wide mobilization of the aorta It is difficult to say how many intercostal arteries can be divided without danger to the spinal cord We know that in cases of aneurysm of the thoracic aorta all intercostal arteries above the diaphragm have been divided without damage to the spinal cord It is however difficult to estimate the amount of collateral circulation in such a case Division of the four upper pairs of intercostal arteries will permit a good exposure of the lower part of the trachea where the anastomosis is performed This procedure did not cause any harmful effect in the 2 cases reported here It is preferable to tie each suture after it is placed in the anterior row The mobilization of the lower lobe is facilitated after division of the pulmonary ligament The use of chromic catgut for the anastomosis I believe, is an important technical detail in order to diminish the formation of suture granulomas When the anastomosis is completed the suture line should be covered by the mediastinal structures or preferably a pleural flap

Tracheostomy was not found necessary in these cases

SUMMARY

Resection of a tuberculous stenosis with a bronchotracheal anastomosis on the left side is preferred to plastic reconstruction with a dermal graft A wide mobilization of the aorta will make the operation technically possible The experience of 2 cases with left-sided bronchotracheal anastomoses are reported

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MODIFICATION OF BROCK'S VALVULOTOME RING

Gerónimo N Guastavino, M D *
Buenos Aires, Argentina

AMONG the better known valvulotomes, Brock's is considered practical because of its small size and easy manipulation It may be introduced into the auricular appendage and withdrawn with the loss of a very small quantity of blood It consists of adding a blade to the index finger There is the inconvenience of having to withdraw the finger from the auricle to apply the instrument This entails extra trauma to the heart, and although of no practical inconvenience to an experienced surgeon it places extra strain on the heart

Our object has been to permit the introduction and withdrawal of Brock's valvulotome, leaving the finger in situ For this we have replaced the original fixed ring with another ring with a spring hinge (Fig 1) † This allows the

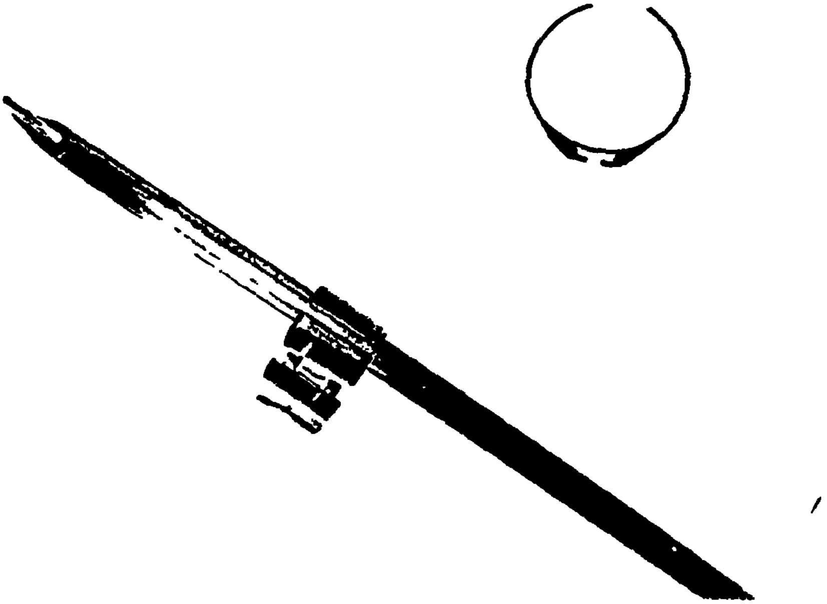

Fig 1—With the valvulotome is the newly devised ring the spring hinge can be seen The free ring is the Brock's original fixed ring

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†Modification manufactured in the United States by Geo P Pilling & Son Co 3451 Walnut St. Philadelphia Pa

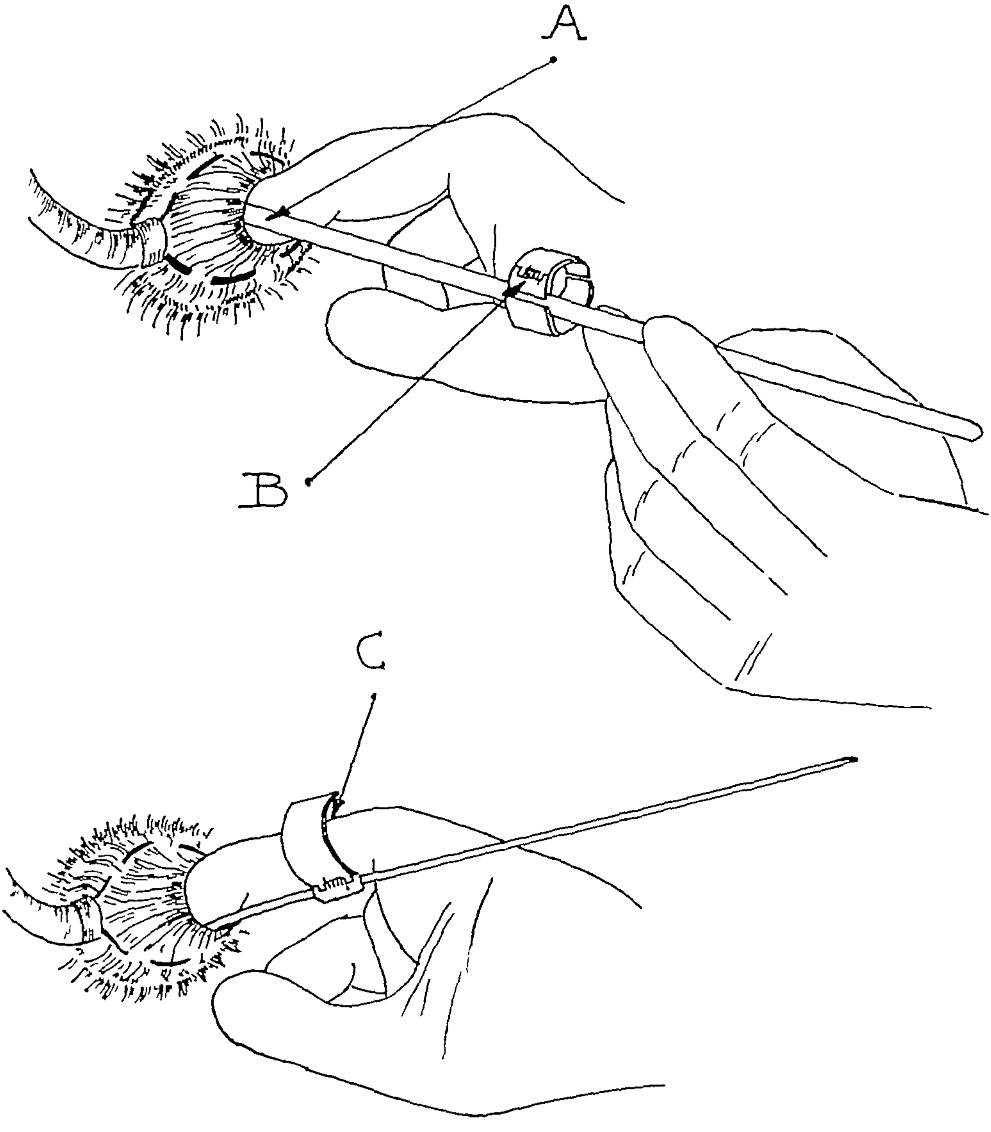

Fig 2 —*A* Introduction of valvulotome without withdrawal of the finger from the atrium *B*, *Spring hinge* *C* *Closing of the ring over the finger after the valvulotome has* been introduced

introduction of the valvulotome into the auricle, one then closes the ring over the proximal aspect of the index finger, without having to withdraw it (Fig 2) It then allows the withdrawal of the instrument once it has completed its object by the opening of the ring that fastens it to the index finger

We consider this an improvement to this type of valvulotome and on using it we have found it both practical and simple

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-sixth Annual Meeting of the American Association for Thoracic Surgery will be held May 7, 8 and 9, 1956, in Miami Beach, Florida. Headquarters will be at the Hotel Fontainebleau.

Requests for Hotel Reservations

These should be mailed directly to Mr. Jack Slone, Director of Sales, Hotel Fontainebleau, Miami Beach, Florida. Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure. If accommodations are desired elsewhere in Miami Beach, please communicate directly with the hotel of your choice.

Thoracic Surgical Forum

The Thoracic Surgical Forum will be continued as a special session at the 1956 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferral to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgical Forum papers will be published together in one issue of the JOURNAL. Maximum length 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of all papers at the 1956 meeting must be received on or before Dec. 15, 1955, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgical Forum," or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five, repeat, five copies of each abstract must be sent to the Secretary of the Association, Dr. Paul C. Samson, 3959 Happy Valley Road, Lafayette, California. They should not be sent to the Editor.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in the JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Julian Johnson, University Hospital, 3400 Spruce St., Philadelphia 4, Pa., before Dec. 15, 1955.

(Continued on next page.)

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec 15, 1955, otherwise, the applications will be deferred for consideration until the 1957 meeting

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

Erratum

In the article, "Traumatic Chylothorax and Thoracic Duct Ligation," by Joseph Goorwitch, which was published in the May, 1955, issue of the JOURNAL, pages 467-479, the following error occurred In *Table III—Cont'd concerning the case of Seaman*, quoted by Goorwitch, it was stated that the treatment was by "thoracenteses followed by ligation of duct in chest" Actually, Dr Goorwitch should have stated that the treatment was by "thoracenteses followed by *plastic repair of the duct without ligation*"—EDITOR

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Surgical Forum Issue

THE RATIONALE OF ANASTOMOSIS OF THE RIGHT AURICULAR APPENDAGE TO THE PULMONARY ARTERY IN THE TREATMENT OF TRICUSPID ATRESIA

Application of This Procedure to a Case of Cor Triloculare

Elliott S Hurwitt, M D, Dennison Young, M D (by invitation), and
Doris J W Escher, M D (by invitation)
New York, N Y

PALLIATIVE surgery by means of the Blalock[1] or Potts[2] type of anastomosis has been less satisfactory for tricuspid atresia than for the tetralogy of Fallot. An analysis of the first 1,000 cyanotic cardiac patients to be operated upon by Blalock and his group showed that 21 per cent of 62 patients with tricuspid atresia died at or shortly after operation, with a total mortality of 26 per cent eight months postoperatively.[3] In the series reviewed by Sommers and Johnson[4] more than two thirds of all patients with tricuspid atresia died before one year of age because of congestive heart failure and anoxia whether or not surgery had been performed. In 4 infants shunts of the types just described had been constructed with no striking increase in longevity.

On Nov 15 1954 in the Forum on Fundamental Surgical Problems of the American College of Surgeons a new surgical approach to the treatment of atresia of the tricuspid valve was described by Warden, DeWall and Varco.[5] They performed an anastomosis between the tip of the right auricular appendage and the main pulmonary artery in dogs with suture-obliteration of the orifice of the tricuspid valve. Certain theoretical advantages were postulated for this procedure in contrast to the extracardiac shunts of the Blalock or Potts type. Utilization of the pumping action of the right auricle in propelling the systemic venous blood into the pulmonary circulation and avoidance of recirculation of blood already partially oxygenated were considered to be factors in support of this concept.

From the Surgical and Medical Divisions, the Montefiore Hospital, New York City.

Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City, N J, April 24 to 26, 1955.

The attention of the cardiovascular group at this hospital became focused on this situation because of a desperately sick, intensely cyanotic infant in whom a clinical diagnosis of tricuspid atresia was made Extensive conference deliberation, abetted by the demonstration in the laboratory of the technical facility with which such an anastomosis may be constructed in the normal dog, led to a decision to attempt this anastomosis in the case under consideration, provided certain physiologic and anatomic conditions were substantiated at exploratory thoracotomy Although the operation was unsuccessful, and a cor triloculare was found at autopsy, the total experience has provoked a critical analysis of the problem

CASE REPORT

D P, an intensely cyanotic 4 month old white boy, weighing 9 pounds, was transferred to the Montefiore Hospital from the Staten Island Hospital by Dr Oscar Race and Dr J Silverman on Nov 18, 1954 (Admission No 69742) Birth weight was 7 pounds, and cyanosis appeared promptly The constant administration of oxygen became practically obligatory following the onset of an upper respiratory infection on November 13 On admission here, he was afebrile and grossly underdeveloped, but not dyspneic, and had no clubbing of the fingers or toes There was no distention of the veins in the neck, and the lungs were clear The heart was moderately enlarged, and there was a short rough systolic murmur over the second and third interspaces, to the left of the sternum All heart sounds were described as being of normal quality, including the pulmonic second sound The liver edge was felt 2 fingerbreadths below the right costal margin, and there was no edema of the trunk or extremities The presence of frontal bossing and a widely open anterior fontanel suggested a mild hydrocephalus in addition to congenital heart disease

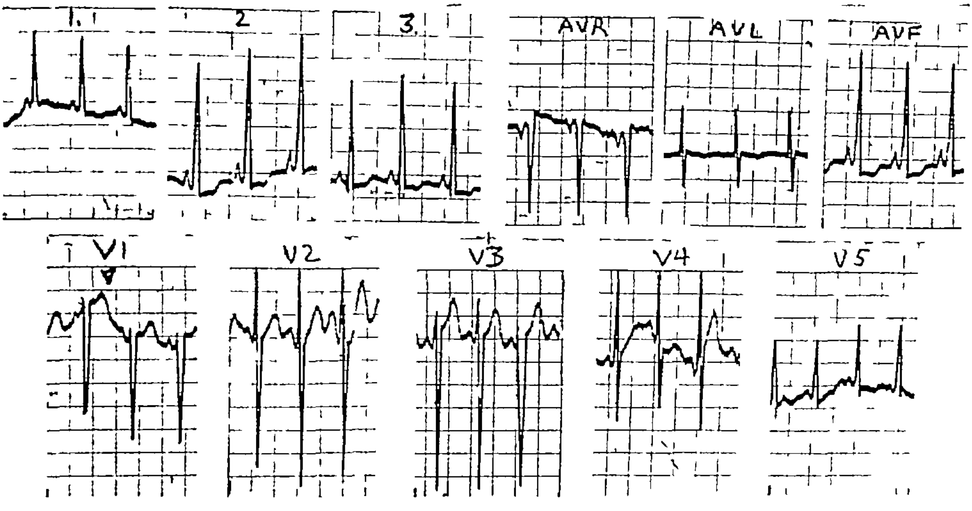

Fig 1—Electrocardiographic tracings showing absence of right ventricular preponderance (see text)

The hemoglobin was 14 Gm per cent, with an erythrocyte count of 5 09 million The electrocardiogram showed absence of right axis deviation in the standard leads, an absent R wave in Lead AVR, and an extremely small R wave in Lead V_1 (Fig 1) These findings are distinctly abnormal at this age and indicate left ventricular enlargement Roentgenograms and cardiac fluoroscopy revealed a picture strikingly similar to that of tetralogy of Fallot The pulmonary vascularity was diminished The main pulmonary artery segment showed a concavity, and the blunting rounding and elevation of the lower left cardiac border in the posteroanterior view suggested the appearance of the right ventricle as commonly seen with the tetralogy The left anterior oblique position showed what appeared to be a small left ventricle, a mildly enlarged inflow tract of the right ventricle, and a normal appearing right atrium (Fig 2)

The diagnosis of tricuspid atresia was based on the association of severe cyanosis with the electrocardiographic rather than the roentgenographic features During the 20-day period of hospitalization, there was progressive deterioration in the infant s condition and he experienced several almost lethal episodes of severe dyspnea with accentuation of cyanosis

An operation was undertaken on Dec. 8, 1954. Preoperative medication consisted of morphine sulfate, 1/60 of a gram, and scopolamine bromide, 1/600 of a gram Under satisfactory general anesthesia of vinyl ether and oxygen by Dr Edith Kepes, an intratracheal tube was passed and the child was placed in a tub of ice and water for 12 minutes until his temperature reached 90° F During the operation his temperature drifted over a 25 minute period to 82° F, where it remained for 35 minutes and he was carried in a light plane with high concentrations of oxygen With the child in the supine position the right pleural cavity was entered through a submammary incision traversing the third interspace and transecting the sternum The incision was extended across the left anterior thoracic wall and the left pleural cavity was entered through the third interspace for additional exposure (Fig 3) The lungs appeared normal there were no adhesions and no increase in vascular collateral channels in the mediastinum The thymus extended low onto the anterior surface of the pericardium and was mobilized and retracted with traction sutures The pericardium was incised vertically anterior to the right phrenic nerve and a horizontal extension made overlying the region of the base of the heart toward the left phrenic nerve The pericardial flaps were held apart with traction sutures The right auricular appendage

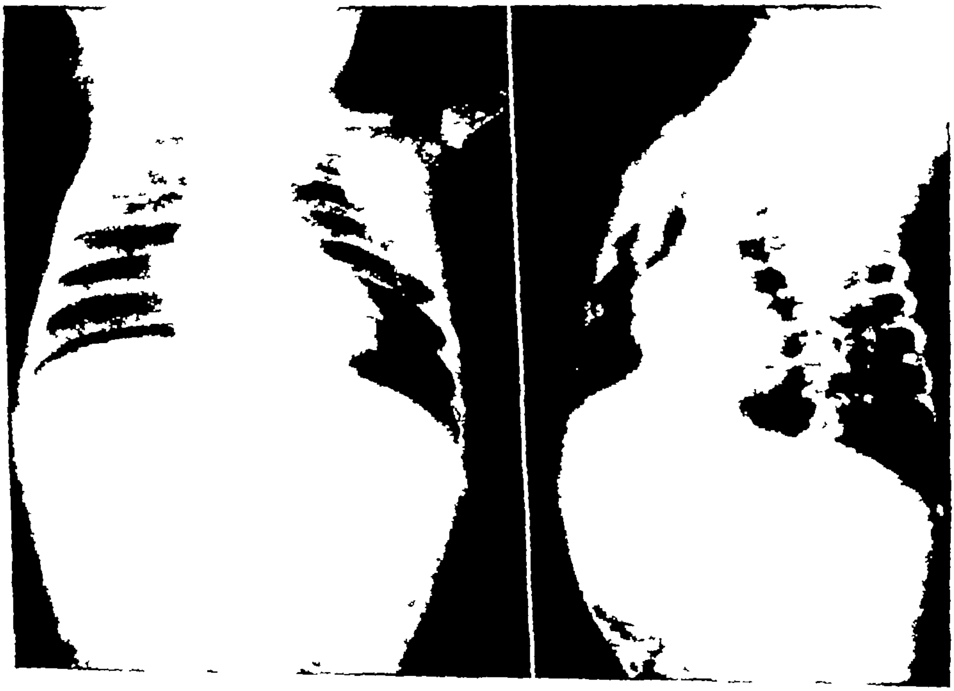

FIG 2—Posteroanterior and left anterior oblique chest roentgenograms suggesting tetralogy of Fallot (see text)

was a dense blue in color, and both it and the right auricle were considerably enlarged an moderately tense The superior vena cava was in the normal relationship, as was the aorta which measured 12 mm. in diameter at its base The main pulmonary artery was hypoplastic measuring 6 mm in diameter at its origin, and appeared to arise from a rudimentary righ ventricle (Fig 4) The small pulmonary artery appeared collapsed and extremely soft There was no palpable thrill to suggest either a patent ductus arteriosus or a pulmonar valvular stenosis, and the pulmonic cusps were not rigid or thickened

During this exploration the cardiac action was extremely erratic, periodically becomin very slow and irregular, and speeding up when warm saline was sprayed over the heart Th systolic blood pressure fell from 80 to 50 mm Hg During periods of better function, direc pressure measurements were obtained sequentially from the right auricular appendage an the main pulmonary artery, and recorded on a multichannel electronic recording apparatus* The preliminary report indicated that the pulmonary arterial mean pressure was 11 mm Hg, i contrast to 7 in the right auricle Oxygen saturations of the blood, taken at the same tim as the pressures, were determined to be 22 5 per cent from the right auricle and 27 5 per cen from the pulmonary artery, as measured on a Waters Conley oximeter The arterial oxygen saturation in the ascending aorta was 25 per cent, initially, and 32 per cent from the aortic arch, 12 minutes later Because of the child's poor and variable condition, these data were of qualified value only, other than to point up what appeared to be a lack of pulmonic blood flow

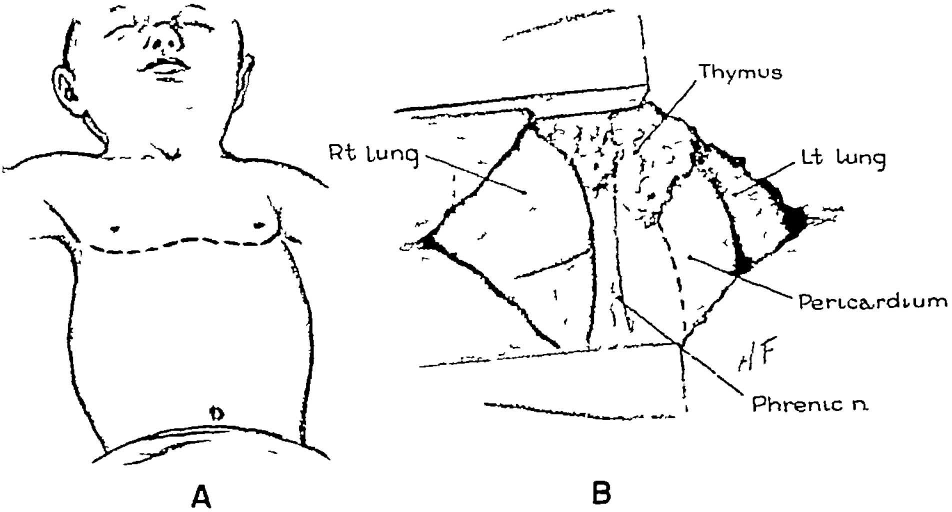

Fig 3 —Diagram of operative position incision and exposure

Since the clinical state of the patient precluded accurate evaluation of the pressure gradient between the pulmonary artery and right auricle, and no patent ductus arteriosus had been found, it was elected to attempt an anastomosis between the right auricular appendage and the pulmonary artery The sulcus between the origin of the pulmonary artery and the aorta was dissected, mobilizing the first portion of the pulmonary artery A Potts type of curved multitoothed clamp was applied over the base of the pulmonary artery in an attempt partially to occlude this, a Satinsky clamp was placed over the mid portion of the right auricular appendage, and the tip of the appendage was amputated (Fig 5) At this point, with a body temperature of 84 5° F, the heart again slowed considerably, went into cardiac arrest, and gave only an occasional beat despite vigorous attempts at resuscitation, including continuous rhythmic cardiac compression, intermittent inflation of the lungs, intracardiac injections of epinephrine and calcium chloride and rewarming with intrathoracic hot saline to 95° F. As soon as the heart had slowed, the clamp had been removed from the pulmonary artery and the lungs had been expanded.

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*Manufactured by Electronics for Medicine Inc. New York City

An effective beat could not be re-established, but the heart was still contracting unpredictably when it was elected to complete the anastomosis in the hope that an increased

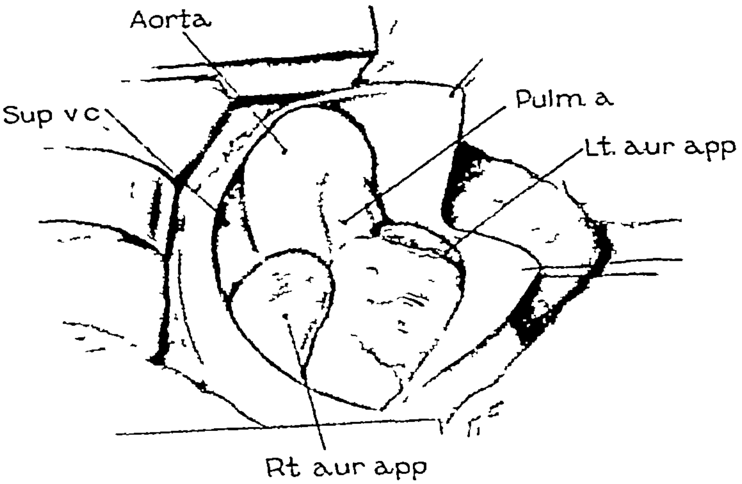

Fig. 4.—Pericardium opened showing hypoplastic pulmonary artery.

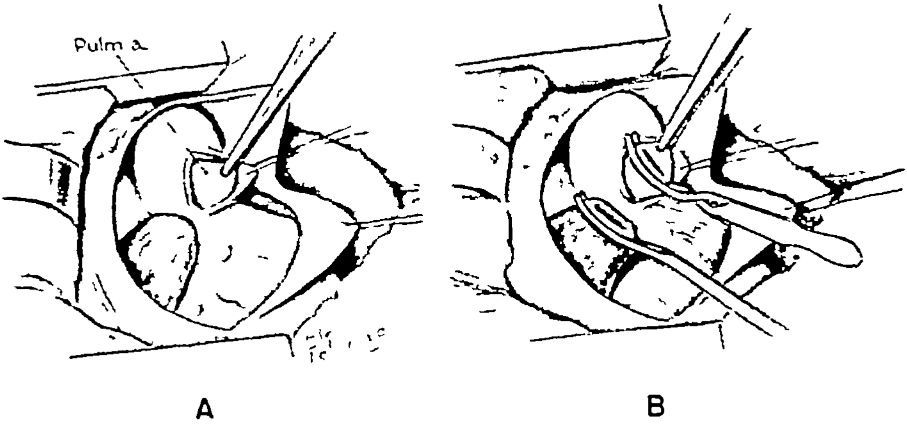

Fig. 5.—Preparation of pulmonary artery and right auricular appendage for anastomosis.

pulmonary blood flow might provide the possibility of survival. Trabeculae near the tip of the right auricular appendage were divided. A finely ground thin walled multitoothed bulldog clamp was applied over the base of the pulmonary artery in such a way as to leave an adequate lumen. A 5 mm vertical incision was made in the anterior wall of the pulmonary artery between the jaws of the partially occluding clamp. An anastomosis was constructed between the tip of the right auricular appendage and the incision in the pulmonary artery with a continuous suture of No 5 0 Deknatel braided silk on a curved Atraumatic needle. The anastomosis was accomplished without difficulty, since it was possible to bring the distended and enlarged right auricular appendage over to the pulmonary artery with no tension or distortion (Fig 6) Following removal of the clamps, cardiac resuscitation still could not be achieved It was felt that the final precipitating cause of death may have been the short period of occlusion of the pulmonary artery superimposed on a state of severe anoxia in a badly crippled heart

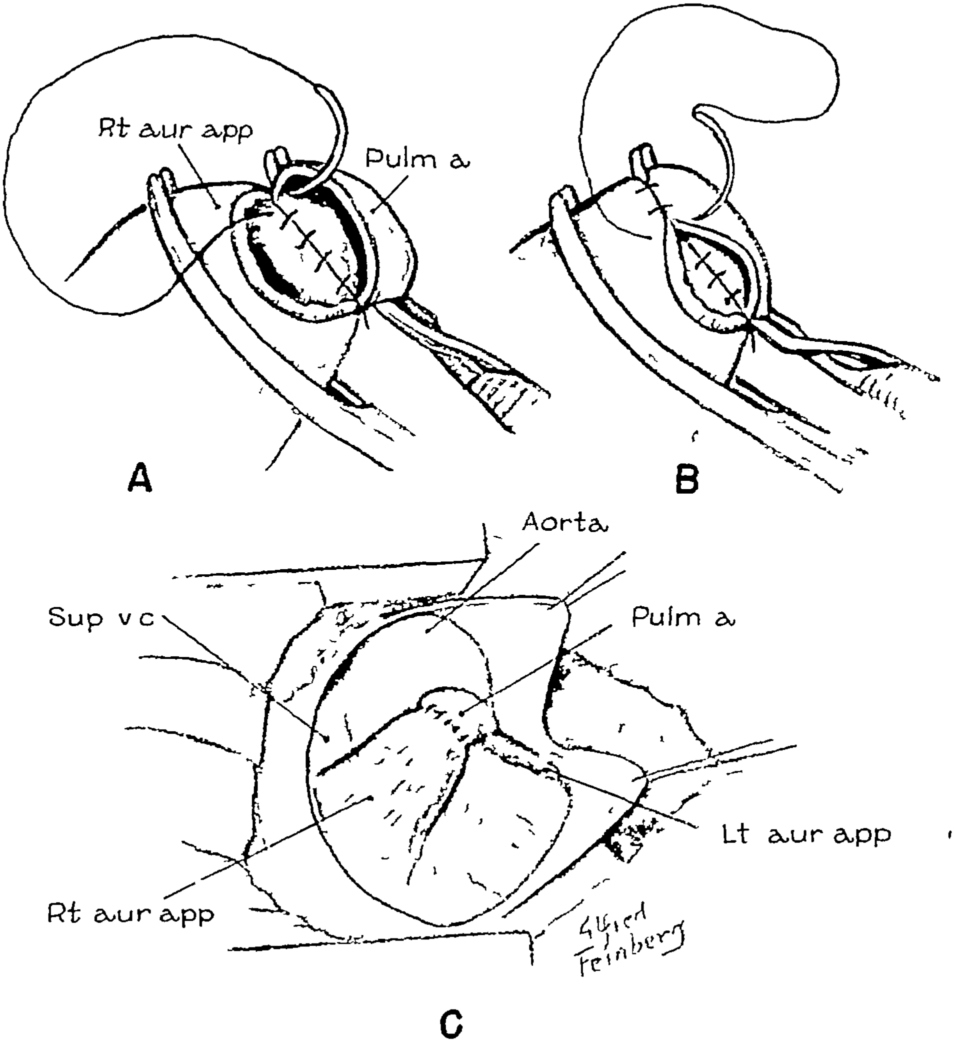

Fig 6—Technical details of anastomosis

At autopsy there was found a cor triloculare with a large single ventricle and a rudimentary conus of a right ventricle Both auricles communicated freely with the dilated, hypertrophied common ventricle, by a large mitral and a rudimentary tricuspid valve There was hypoplasia of the pulmonary artery and the pulmonic valve was bicuspid There was a small, probe patent foramen ovale, the ductus arteriosus was obliterated No evidence of congestive heart failure was found It was felt that the common ventricle represented both the left and right ventricles with no evidence of septation other than at the site of one of the papillary muscles. Permission to examine the brain was not obtained, so that the question of early hydrocephalus could not be resolved.

DISCUSSION

From the onset, it was apparent that there were certain important differences between the provocative experimental situation of Warden, DeWall, and Varco and the human case of cyanotic congenital heart disease, of which tricuspid atresia might be a component. In a case of true tricuspid atresia, the presence of an interauricular septal defect is obligatory for survival. The maldevelopment of the right ventricle, which appears to be the primary defect, may also involve the main pulmonary artery.[6] The blood reaching the lungs does so largely by way of a patent ductus arteriosus, bronchial arteries, or collateral mediastinal vessels.

The success of an anastomosis designed to carry blood from the right auricle to the pulmonary artery depends upon a pressure gradient in the proper direction. In a true tricuspid atresia with a hypertrophied, hypertensive right auricle, this gradient would almost certainly be present and demonstrable unless masked or reversed by the additional presence of a patent ductus or ventricular septal defect. Cases of tricuspid atresia may occur, however, with deep cyanosis by virtue of a large interatrial septal defect without having enough reduction of pulmonic flow to provide the necessary pressure differential.

The association of left ventricular preponderance in the electrocardiogram with the clinical and radiographic features of Fallot's tetralogy is usually indicative of tricuspid atresia and in infancy the electrocardiographic evidence is considered to be more reliable than the roentgenographic interpretation. Others have also noted, however, that a similar electrocardiographic pattern may be found in a variety of cyanotic lesions characterized by a common ventricle.[7] The unreliability of this finding as pathognomonic of tricuspid atresia has not been widely appreciated and resulted in the diagnostic error in the present case.

It had been hoped that one might be able to confirm the clinical diagnosis by means of differential pressure and oxygen determinations during the operation. Actually this patient's condition prevented definitive analysis, so that the decision to proceed was based on the clinical data and the hope that an increased flow of blood to the lungs might improve the possibility of survival. The demonstration of a cor triloculare at autopsy indicates that a Blalock type of shunt would probably have been preferable as suggested by Taussig,[8] although an atriopulmonic shunt might have functioned in view of the markedly restricted pulmonic blood flow caused by the rudimentary right ventricular conus.

At the time of commencing to construct such a shunt, it would be preferable to prepare the right auricular appendage before interfering with the main pulmonary artery. If possible a partially occluding clamp should then be applied to the pulmonary artery. If this is not feasible and total pulmonary arterial obstruction is necessary and/or cardiac arrest should ensue as it did under hypothermia in this instance, the procedure of choice should be an immediate and rapid anastomosis, reserving efforts at resuscitation until this has been completed.

Despite the initial appeal of the atriopulmonic shunt in the treatment of tricuspid atresia, and the comparatively poor results achieved by other methods, there are several factors which suggest that the usefulness of this new procedure will probably be quite limited. The presence of a large interatrial defect may conflict substantially with the amount of blood leaving the right auricle by way of the new shunt. Should auricular failure or fibrillation occur, the pumping action would become ineffectual. If left heart failure or mitral valvular disease were to develop, the pressure gradient might reverse. Acute or chronic pulmonary disease might obliterate the pressure gradient. And, with any significant degree of hypoplasia of the main pulmonary artery, it is doubtful whether a satisfactory anastomosis could be constructed or whether the low-power thrust of the auricle could move an effective volume of blood into the narrowed channel. None of these situations would give cause for similar concern following a Blalock or Potts operation. In addition, although Warden, DeWall, and Varco have observed that the right auricle may fulfill the pumping requirements of the right heart under conditions of experimental abolition or massive infarction of the right ventricle, long term survival studies are not yet available to indicate how long the auricle could maintain its pumping potential against the elastic recoil of the pulmonary arterial tree. The two month survival period recorded by Rodbard and Wagner[9] in dogs with anastomoses of right auricle to pulmonary artery, but without obliteration of the tricuspid orifice, suggests that longer periods of observation might be of considerable value.

Many of the problems presented in this discussion may not be insurmountable. The implication of these considerations and this case report is that further investigation will be necessary before one may state whether or not anastomosis of the right auricular appendage to the pulmonary artery may be beneficial in a case of tricuspid atresia. The circulatory by-pass of the right heart described by Glenn and Patino,[10] anastomosing the azygos vein to the right pulmonary artery, and the anastomoses between the venae cavae and the pulmonary artery referred to by Shumacker[11] represent provocative experiments in this direction.

SUMMARY

1. A critical analysis is presented of the rationale of right auricular pulmonary arterial anastomosis in the treatment of tricuspid atresia.

2. An anastomosis between the right auricular appendage and the main pulmonary artery was performed in a cyanotic infant suspected of having tricuspid atresia.

3. At autopsy a cor triloculare was found with a rudimentary right ventricular conus causing a marked obstruction to pulmonary arterial blood flow.

4. The presence of a pressure gradient from right auricle to pulmonary artery should be demonstrated at operation if this type of shunt is under consideration.

5 The absence of right ventricular preponderance in the electrocardiogram of a cyanotic infant with the radiologic configuration of a tetralogy of Fallot is not pathognomonic of tricuspid atresia

We gratefully acknowledge the generous suggestions of Dr Louis Leiter in evaluating this material

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11 Shumacker H B Discussion of Warden DeWall and Varco

DISCUSSION

DR HARRIS B SHUMACKER Indianapolis Ind —With reference to the paper Dr Hurwitt presented I thought you might be interested in several other experiences with right heart by pass Unfortunately they all ended fatally We have not felt justified in using this operation in cases of tricuspid atresia for our experience with the shunt operation of Dr Blalock in the treatment of this condition has been good We have however done a partial or total by pass in 3 children with conditions with which we have had no success with other methods of treatment One was a very sick child who had truncus arteriosus with pulmonary hypertension and large pulmonary trunks coming off the common one In this case and in one case with complete transposition we simply performed a superior vena cava right pulmonary artery end to end anastomosis Both children succumbed some eight to fifteen hours later We subsequently treated 1 patient with complete transposition of the great vessels with ventricular septal defect and without atrial septal defect by total right heart by pass Since the pulmonary trunk was posterior we could not directly anastomose the right atrial appendage to it and had to interpose a graft We then closed off the tricuspid valve by mattress sutures guided in place with a finger inside the atrium and finally we completely eliminated blood flow from the right ventricle into the pulmonary artery by suture We were pleased to observe that at the completion of the procedure the child was well colored and had excellent peripheral pulses and excellent blood pressure This child unfortunately died rather suddenly about six or eight hours later Study at post mortem failed to explain the mechanism of death The peripheral circulation had been excellent up until the end The autopsy confirmed the complete transposition the large ventricular septal defect the intact atrial septum and the complete by pass of the right heart This experience does demonstrate that at least for a period of hours the human heart can function with the right heart circumvented completely

DR HERBERT E WARDEN, Minneapolis, Minn —I rise for a twofold purpose and will be very brief First, I want to congratulate Dr Hurwitt and his group on their presentation and their courage in attempting surgical amelioration of this dismal form of congenital heart disease Second, I want to respond to the inquiry regarding the results of our long term survivors The entire group of animals that was reported last fall, in which a tricuspid obstruction had been produced followed at a later stage by a right auricular pulmonary artery anastomosis and complete occlusion of the tricuspid valve, is alive, the longest of which is two years, the shortest six or seven months We have felt, as was suggested here this morning, in view of the fact that most forms of congenital tricuspid atresia have associated abnormal intracardiac shunts, that the method warranted further evaluation in the presence of such a defect We are attempting to do this by first producing an artificial ductus and, at a second operation, by suturing the tricuspid valve and at the same time creating an interatrial septal defect These animals will then be treated by a corrective right auricular pulmonary artery shunt This group is being studied now and it is too early to make any conclusive report

AUTOGENOUS THORACIC AORTA GRAFTS OF PERICARDIUM AND NYLON NET USING A THROMBIN-FIBRINOGEN COAGULUM

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DENVER, COLO.

TODAY, a number of congenital, traumatic, and degenerative lesions that involve the thoracic aorta may be adequately resected, but the problem of finding an ideal long-term replacement for the excised aortic tissue remains to be solved. The lack of an available autogenous artery has resulted in widespread investigation to find an aorta substitute using homologous and heterologous vessels, diverse plastic prostheses, and ingenious combinations of nonvascular tissues. Certain undesirable features associated with homologous grafts not seen in autogenous grafts, and the additional problems associated with the maintenance of an aortic vessel bank stimulated a search for a simple practical method of making aortic grafts from a suitable body tissue that would be readily available and expendable at the time of thoracotomy. This paper will outline the method developed in dogs to meet these needs by making thoracic aorta grafts from autogenous pericardium, nylon net, and a coagulum of thrombin and fibrinogen.

MATERIALS AND METHODS

Mongrel dogs weighing from 18 to 65 pounds were used. Intravenous pentobarbital sodium (Nembutal) was used for anesthesia and intermittent positive pressure administered by a M.S.A. demand pneophore apparatus. The left hemithorax was exposed through the fifth interspace. A large sheet of pericardium was removed and trimmed free of adhering fat. The aorta just distal to the ligamentum arteriosum was selected as the site for insertion of the graft because it was thought that in this location the graft would be subjected to maximum stress.[1] The left subclavian artery and distal aorta were mobilized and a variable number of intercostal arteries divided. The diameter of the aorta was carefully measured with calipers and a glass suture tube or test tube of appropriate size selected for fashioning the graft. Except for certain initial short length grafts in which the aorta was only divided, a segment of aorta approximately three-fourths the length of the graft was usually resected.

A siliconized polythene shunt was devised that protected the dog from any untoward effects of aortic cross-clamping. The proximal flanged end was tied into the left subclavian artery and the distal end was quickly inserted into the descending aorta through a small incision and held there by an outside constricting double loop of oiled umbilical tape. The intervening aorta was excised between Potts coarctation clamps.

Nylon net* of the type described by Vargas and Deterling[2] was selected to prevent dilatation and aneurysm formation which had been shown to occur when

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From the Research and Development Service, Fitzsimons Army Hospital, Denver, Colo.
[illegible] Buffalo General Hospital, Buffalo, N. Y.
Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery, at Atlantic City, N. J., April 24 to 26, 1955.
*Supplied by Ethicon Suture Laboratories.

pericardium was used as a graft in the thoracic aorta.[3,4] To eliminate certain disadvantages associated with Vargas and Deterling's method of rolling out a preformed nylon net tube over a graft at the completion of the anastomoses and anchoring it by sutures, a method was developed for causing the pericardium and nylon net to adhere together as one tissue. Topical thrombin* and fibrinogen† were combined to form a sticky, physiologic coagulum. The outer surface of the pericardial sheet was first covered with a layer of thrombin solution (2,000 NIH units per c.c.). A moderately heavy layer of preserved fibrinogen powder was then sprinkled on this surface. A rectangular piece of nylon net, fashioned to appropriate size, was immediately placed on this coated pericardial surface. Within several minutes the fibrinogen was in solution, the net and pericardium became adherent and could be handled as one tissue. These

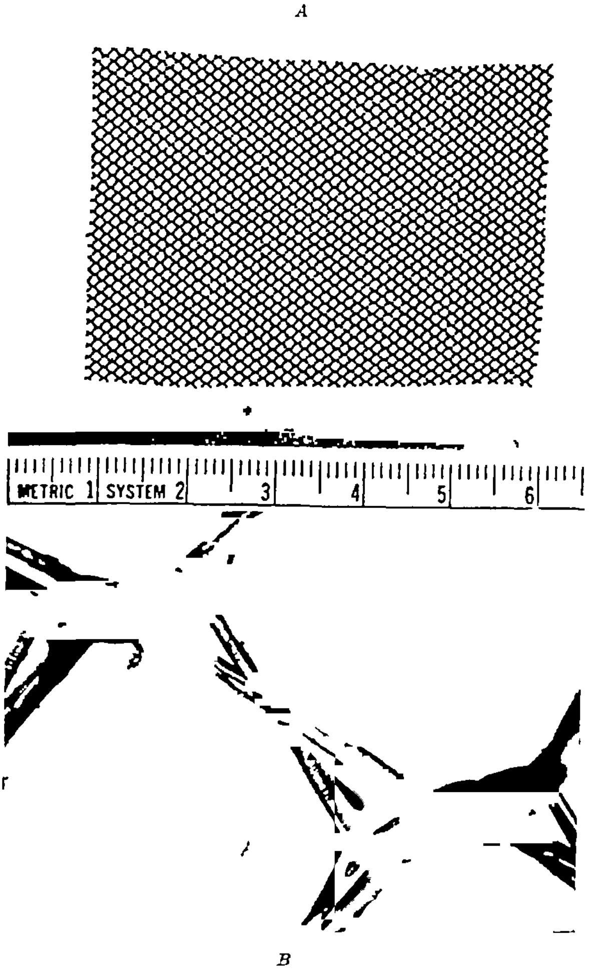

Fig. 1.—Nylon net. *A*, Gross appearance. *B*, Photomicrograph magnified ×70. Note knotting of fiber junctions.

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*Thrombin topical (bovine) supplied by Parke, Davis & Company.

†Fibrinogen (human) Parenogen supplied by Cutter Laboratories, Berkeley, Calif.

two were then wrapped around the oiled glass tube, the inner pericardial surface facing the tube and the net facing the outside By means of a continuous mattress suture of No 5 0 arterial silk, reinforced by an outer whipping suture, a cylinder was formed that could be easily slipped off the glass tube, ready for use

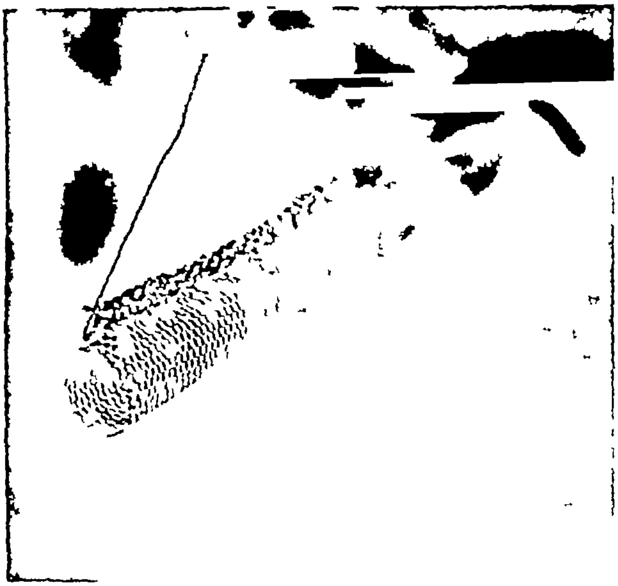

Fig 24 —Oblique end view of newly made graft partially off glass tube

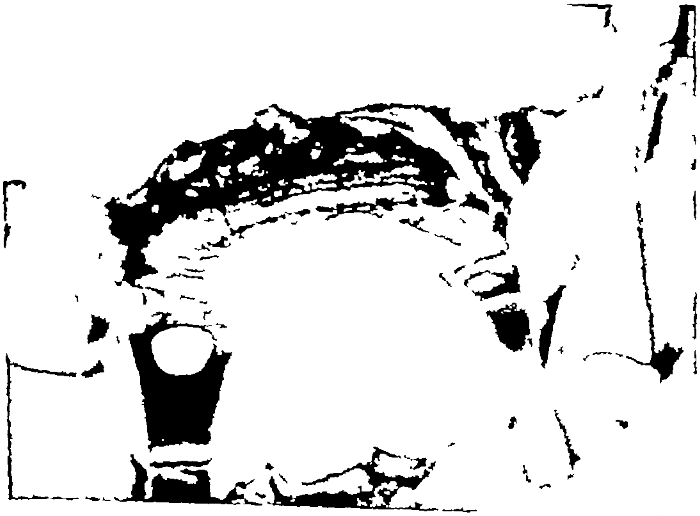

Fig 25 —Operation view of graft following anastomoses to aorta graft longitudinal suture cuff seen end on

Grafts varying in length from 2 to 7 cm and in diameter from 8 to 15 mm were anastomosed to the aorta by interrupted everting mattress sutures of No 5 0 arterial silk The occasional slight tendency of the net and pericardium to separate at the end of the graft when the suture needle was inserted was easily controlled as one became familiar with handling the graft. Special care was taken to insert the suture needle behind at least one crossing of the nylon net fibers. Because these nylon fiber junctions were knotted, raveling was prevented and a sound anastomosis ensured. A cuff of a graft approximately 1 to 2 mm. long was usually everted.

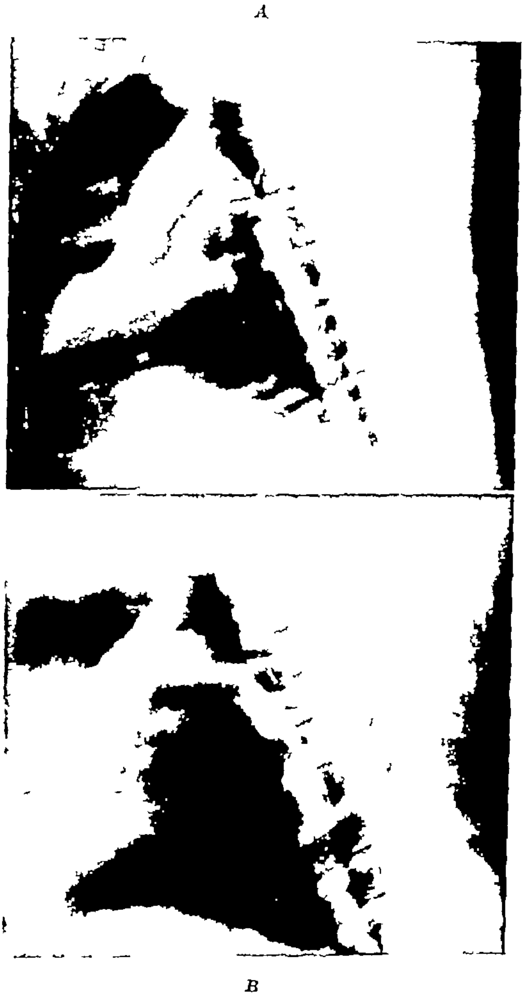

Fig. 3.—Representative aortograms. Silver clips placed adjacent to graft aorta anastomoses at surgery. *A*, Five months. *B*, eight months.

Upon completion of the anastomoses, the shunt was removed by suturing the distal aortic incision and ligating the subclavian artery at the aortic arch. Two silver Cushing brain clips were placed on adjacent tissue to identify the superior and inferior extent of the graft for later x-ray. The dogs received daily penicillin for approximately one week and were followed postoperatively by palpation of femoral pulses, chest x-rays and aortograms, reoperation and necropsy. Gross specimens were photographed and histologic sections appropriately stained by hematoxylin and eosin van Gieson, Verhoeff (elastic), and special histochemical techniques and stains to be mentioned

Physical limitations made it necessary to develop a method of aortography that would eliminate the need for arterial cutdown and catheterization In the right lateral position the point of maximum cardiac impulse was usually palpated about the left fourth or fifth interspace approximately 4 to 6 cm posterior to the sternum A No 18 needle mounted on a 10 c c syringe, was introduced at this site at approximately a 45 degree angle, posteriorly and medially until it entered the left ventricle This position was confirmed by drawing back bright red blood and then 10 c c of 35 per cent Diodrast was quickly injected Eight exposures, at one-half second intervals, were made on a Sanchez Perez seriograph Occasionally, the right heart was accidentally entered and the aortogram would be repeated immediately A number of animals had two or more aortograms without untoward effects Recently, Smith and his associates have reported the use of a transventricular technique stating preference for the subxiphoid approach

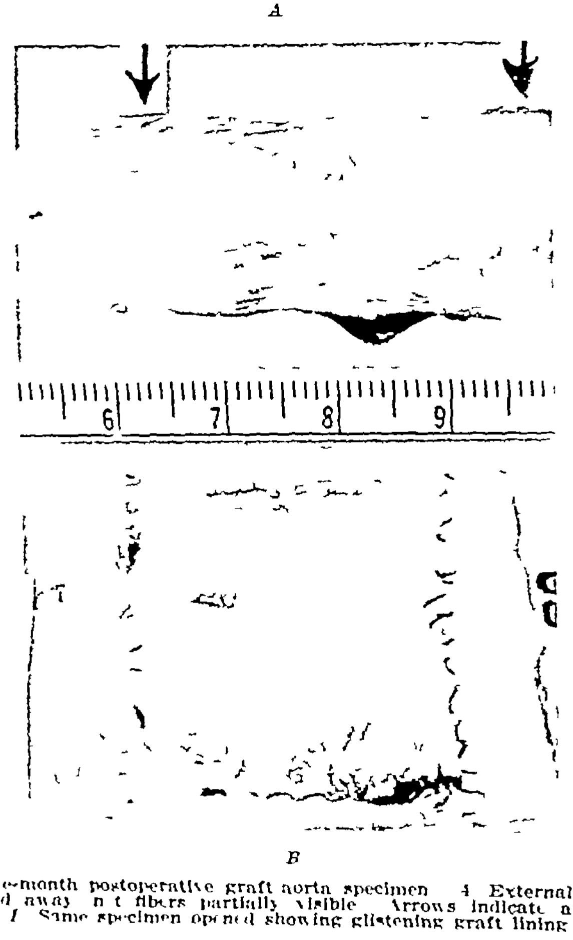

Fig 4 —Five-month postoperative graft aorta specimen A External appearance Lung has been stripped away n t fibers partially visible Arrows indicate anastomoses between graft and aorta B Same specimen opened showing glistening graft lining and thickened graft wall

RESULTS

Thirty-five dogs included in this study were autopsied at postoperative periods from one day through eleven months Initially, several dogs died in the immediate postoperative period from the effects of aortic cross clamping before the shunt was devised Although their grafts were examined, they were not included in this group Necropsy was performed at regular short

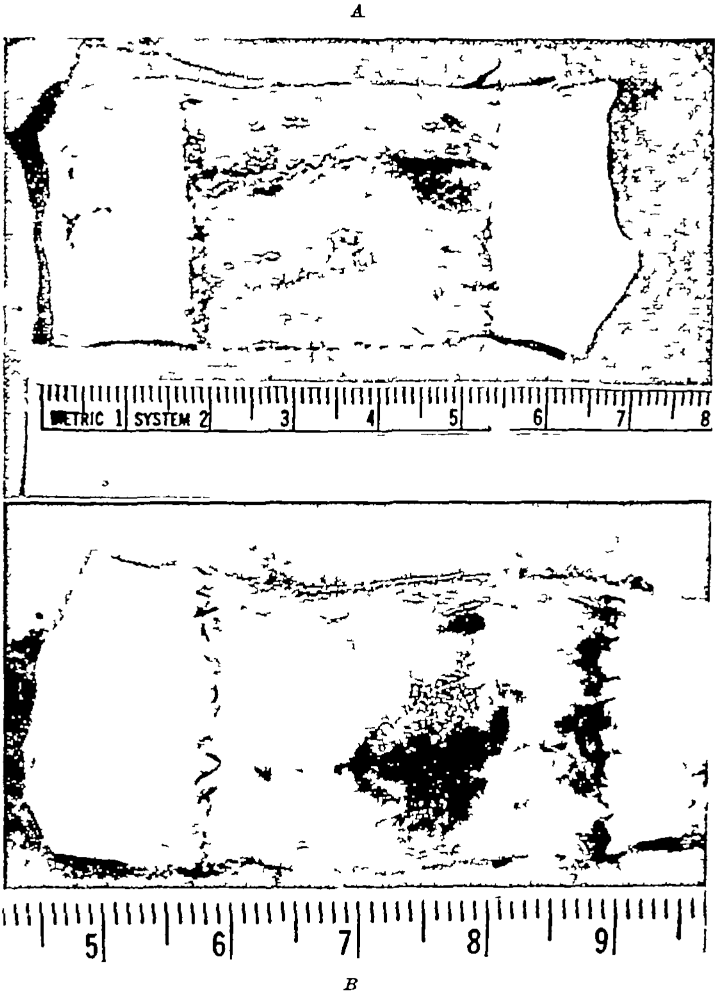

Fig 5—Graft and aorta opened longitudinally *A*, smooth layer lining graft, redness disappearing one week *B* Mural thrombus in central graft with early yellow and orange discoloration along periphery of thrombus four months

intervals during the first three weeks and thereafter at approximately monthly intervals Of the total, 2 dogs died from dehiscence of the anastomotic suture line, both secondary to adjacent infection, 1 at eight days due to a localized abscess, and the other at forty-seven days due to infection from a retained surgical sponge Another died at three months from mesenteric and peripheral emboli originating in a thrombus at a technically faulty distal anastomosis Several dogs dying of unrelated causes at later periods were also included

The majority of the dogs were alive and active at the time of elective reoperation and autopsy

Dogs past the first postoperative month had an aortogram before elective sacrifice and a number had additional aortograms during their postoperative course No graft showed significant dilatation or constriction although several displayed some narrowing at the sites of anastomoses In over 60 intracardiac aortograms there was no instance of extensive bleeding myocardial damage or death directly attributable to the method The elastic properties of the nylon net allowed the graft to have a certain amount of expansile pulsation observed at the time of the original operation and also at reoperation months later This was always less pronounced than that seen in the proximal aorta Adjacent tissue and lung soon became adherent to the graft and occasionally direct vascular communications were observed

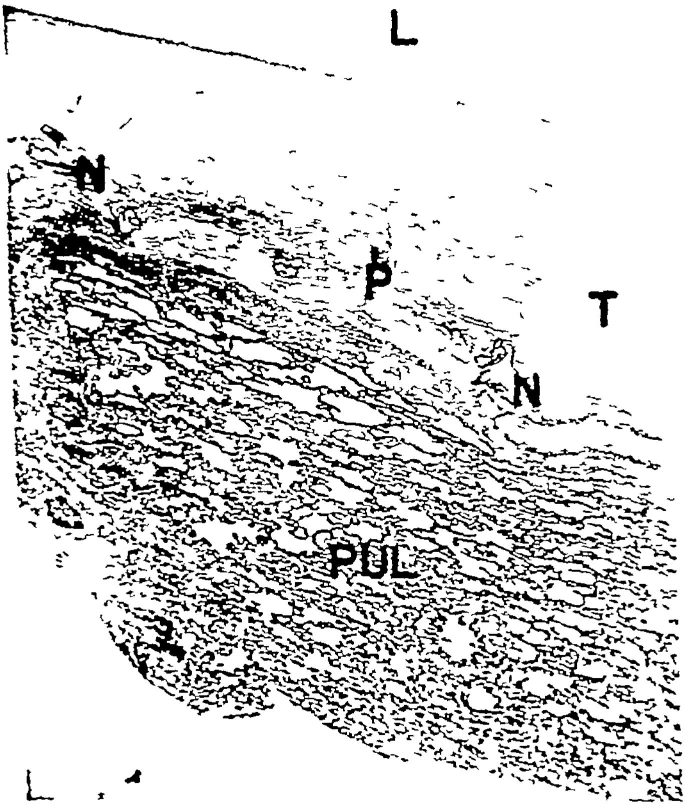

Fig 6 —Photomicrograph of central area of graft with organizing mural thrombus one and one-half months Thrombus intimately adherent to pericardium and developing smooth surface It blended gradually into pseudointima covering graft. The thrombin-fibrinogen coagulum has been replaced by fibrous tissue *L*—lumen *T*—thrombus *P*—pericardium *N*—site of nylon net (fragmented during preparation of specimen) *PUL*—adherent pulmonary tissue (Hematoxylin and eosin stain 32 mm microtessar)

By four to six hours postoperatively a red patchy deposition of blood elements could be seen on the surface of the pericardium During the next several days this usually progressed to a velvety layer of blood cells and fibrin that could be partially scraped off the pericardium with a fingernail At the end of one week, this layer had become a paler, rather homogeneous, fibrinous coagulum with a smooth surface that blended with the intima advancing from the aorta By two weeks, this pseudo-intima was becoming more fibrinous with a surface layer that assumed an intimalike function in later weeks

The thrombin-fibrinogen coagulum between the pericardium and nylon net was invaded by new capillaries at the end of one week following an earlier period of cellular infiltration By two weeks, this substance was partially replaced by fibrous tissue binding the nylon net to the pericardium A similar fibrous

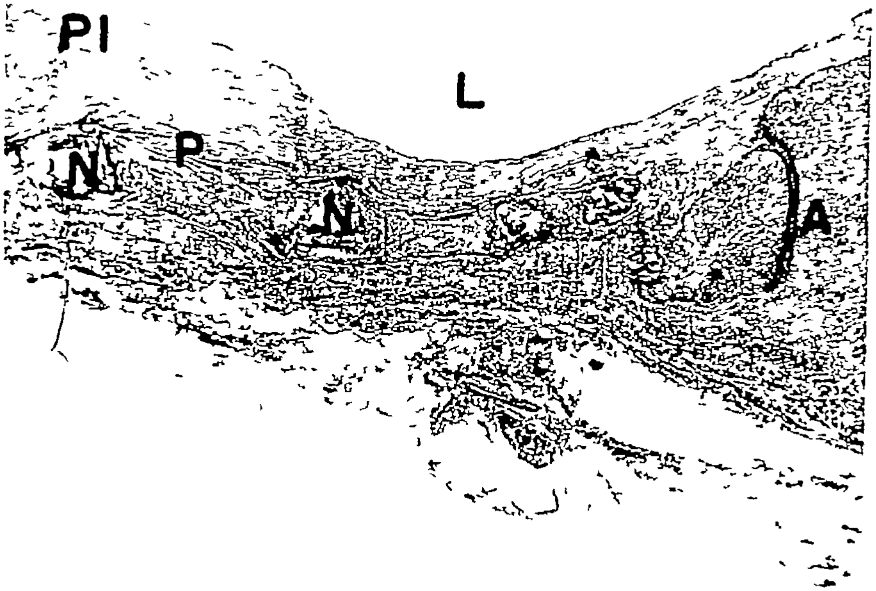

Fig 7—Photomicrograph of aorta-graft junction eight months Note firm union of aorta and graft and blending of intima from aorta with pseudointima of the graft *A*—aorta *P*—pericardium *PI*—pseudointima *N*—site of nylon net (fragmented in preparation of specimen) *L*—lumen (hematoxylin and eosin stain 48 mm micro tessar

reaction occurred outside the nylon which contributed to the progressive thickening of the graft wall The pericardium maintained its normal appearance, although in two grafts it underwent a moderate but temporary swelling between the second and fifth postoperative days By eight to ten months the pericardium appeared to blend with the adjacent fibrous tissue

Mural thrombi were rather surprisingly common They were most frequently located in the central area of the graft and on surface irregularities These thrombi usually lost their red color and blended with the surrounding pseudointima when examined in later months Yellow and orange stains and patches were also observed in a number of grafts

DISCUSSION

The thrombin-fibrinogen coagulum was effective in holding the nylon and pericardium together It appeared to be well tolerated by the host, becoming replaced by fibrous tissue (further detail on the uses of topical thrombin and fibrinogen is to be published) The nylon net was an effective elastic support that prevented dilatation of the graft, allowed free ingrowth of an adjacent vascular supply and permitted a sound anastomosis between the graft and aorta The pericardium maintained its normal appearance although it seemed to undergo swelling or mild degeneration during the first several days possibly reflecting an interval until it gained a new blood supply Its surface usually became coated to a variable degree by precipitated blood elements which formed a rather homogeneous coagulum that underwent fibrinous change and assumed the function of an intima This layer despite its varying thickness in different grafts as well as in different areas of the same graft blended smoothly with the aortic intima It appeared that the intima advancing from each end of the host aorta seldom completely spanned the graft This left the more central portions of the graft covered by the blood elements which adapted to the function of an intima or progressed to form a mural thrombus Flattened mural thrombi also occurred in irregularities and depressions in the graft as if trying to fill in such areas in an effort to form a more uniform and streamlined lumen These mural thrombi usually lost their granular appearance and eventually developed a smooth surface that blended in with the adjacent pseudo-intima

By two to three months yellow and orange stains and patches could be seen that have been referred to as cholesterol degeneration of the pericardium [3,4] In this study this was observed almost invariably in association with mural thrombi which stimulated a more detailed examination of the phenomenon In older grafts these yellow and orange areas tended to persist as the mural thrombi were losing their identity by organization and functional adaptation If a new layer of blood elements became deposited on the surface of the organizing thrombus to form a new pseudo-intima the remaining yellow area could appear like a subintimal plaque The pericardium itself did not appear to be involved in the process No evidence of calcification or ossification was observed

The discolored area and host aorta for control were studied by the following methods (1) for cholesterol and its esters by Schultz s method[7] (2) for lipid by a modified oil red 0 stain[8] (3) for hemosiderin (iron) by Gömöri s modified method As a result of these histochemical tests and stains it was found that the yellow and orange colors were the result of a variable accumulation of cholesterol lipid and hemosiderin They were concentrated in the mural thrombus and adjacent pseudo intima but apparently not in the pericardium By comparison these substances were not found in the normal aorta The lipid was distributed in the form of minute droplets with no appreciable evidence of acicular slits or lipoid granulomatous reaction The lipid sometimes became more condensed within a fibrous connective tissue base in the deeper more organized layers of the thrombi Hemosiderin and related hemoglobin pigments tended to be distributed at random throughout the organizing thrombus It was postulated that the cholesterol and lipid were derived from the blood stream and the hemosiderin from the breakdown of erythrocytes

Considerable individual variations in blood element deposition and mural thrombosis were present and must have been related to such factors as improper tension on the graft causing surface irregularities and various luminal disproportions between graft and aorta Inherent deficiencies in the pericardial surface may have been a factor, but these same surface phenomena have been observed by the author in nylon *cloth* grafts alone The high blood pressure, large cross section, and rapid turbulent flow peculiar to the thoracic aorta must have been of some importance in the pathogenesis of these phenomena In the absence of gross errors in surgical technique, these grafts did not undergo progressive thrombotic occlusion Autogenous pericardial grafts in the thoracic aorta of the dog have been shown to remain patent on aortography as long as three years[5] Careful histopathologic study of long-term pericardial grafts will be necessary for complete evaluation of the method

SUMMARY

1 Aortic grafts fashioned from autogenous pericardium, nylon net, and a thrombin-fibrinogen coagulum appeared to function satisfactorily for periods up to slightly less than one year Long-term follow-up studies will be necessary for complete evaluation of the method

2 Attention is directed to certain aspects of mural thrombosis and lipid deposition encountered in the grafts

3 An aortic polythene by-pass shunt and a method of aortography by direct transventricular needle puncture are described

I wish to acknowledge the help of Captain James Bowman with certain aspects of histopathologic technique

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DISCUSSION

DR J KARL POPPE, Portland, Ore —I should like to ask Dr Adler whether heparin dissolves the thrombin and fibrinogen coagulum used to hold together his grafts My own experience has indicated the necessity for preliminary moistening of the graft with heparin to prevent clotting during its insertion This seemed particularly true when inserting grafts in the thoracic aorta with a temporary polyethylene tube shunt inside the lumen, permitting a slight but continuous leakage of blood into the graft during its insertion

Orlon fabric grafts moistened with heparin before use tended to leak unduly and fabric grafts without heparin tended to fill with clots during insertion in the thoracic aortas of 10 dogs

This difficulty was corrected in subsequent dogs by making the fabric impervious to initial leakage by impregnating its outer surface with polyethylene film in an autoclave The polyethylene filler permitted the use of heparin on the graft with impunity from clotting, leaking, or fraying of the edges This method differs from that proposed by Shumacker in that only one layer of fabric is used instead of two layers with the polyethylene film between them Reducing the thickness makes the material more pliable and permits greater ease in turning back the cuffs

DR PAUL W SANGER, Charlotte, N C—The search for the ideal substitute for the arterial graft continues This is because the maintenance of an arterial bank is impossible in many situations and also because the homograft still leaves something to be desired For these reasons we have turned our attention to synthetic materials We have used an Orlon knit material which is similar to the material in ladies' hose We have also used nylon woven material which is similar to the weave used for a shirt These materials have met certain strict criteria (1) They can withstand sterilization without loss of properties (2) These fibers are closely constructed to avoid leakage (3) The substance is made of a fine filament with a smooth inner surface (4) The materials are nonirritating when placed in the body and are resistant to breakdown and deterioration (5) Furthermore they are strong when wet, and they resist deformity and stretch in the longitudinal plane under conditions contained in the experimental animal and the human body

They have some disadvantages, however The synthetic tubes used in the past have had a longitudinal seam, and the material has frayed at the cut edge making it necessary to cuff it for an end to end anastomosis with the host vessel This introduced a technical problem of having to sew through four thicknesses of material where the seam laps were superimposed

We felt that a seamless tube would be much more desirable North Carolina State College School of Textiles and Mr John B Sidebotham of Philadelphia worked on this problem with us They devised a method of knitting and weaving a seamless tube for us

(Slide) Angiocardiogram showing the graft is patent with normal blood flow distally and with only minimal indentation at the suture line

(Slide) Graft removed six months after its insertion showing complete covering by glistening pseudoendothelium

(Slide) The walls of the graft are magnified approximately 50 times Dense collagenous tissue is found extending through the meshes of the fabric

(Slide) The characteristic appearance of abdominal and common iliac aneurysms (Courtesy of Drs Creech DeBakey and Cooley)

(Slide) Knit Orlon graft in position after removal of the aneurysm (Courtesy of Drs Creech DeBakey, and Cooley)

We have used this fabric as sleeve grafts in the thoracic and abdominal aortas of 50 dogs, and we and others have also used it in 23 human beings

The strength of an artery depends upon its elastic tissue In homografts, the elastic tissue eventually disappears, while in these plastic grafts the artificial fiber remains intact Thus, this synthetic fiber seemingly serves as elastic tissue

This is a material which is cheap is easily cared for and can be made available to any doctor

DR RALPH DETERLING JR New York N Y—In about 1948, we began to implant aortic homografts into the aortas of dogs and after three years, we were distressed to find calcification spotty deterioration of the elastic framework and thinning of functioning grafts Although we did not encounter aneurysm formation in dogs studied for over five year these degenerative changes appeared to be progressive Approximately three years ago Dr Lester Vargas and I began to use the tulle weave nylon referred to in this paper having selected it because of the wide interspaces elasticity and strength It was used as external support to arterial venous and pericardial grafts in dogs so as to correct tendency to dilatation of the grafts When we reported this work one year after its inception we were quite delighted with the results

(Slide) On the left is an aortogram which shows a graft of the external jugular vein in the thoracic aorta of a dog at about one year There is elongation and aneurysmal dilatation of the implant On the right is a similar graft supoprted by the tulle net for one year, and there is no significant change from the time of implantation

We have now followed these dogs for over three years and I must rise to state that 3 of about 15 have shown significant late dilatation despite external support by nylon net A careful dissection of these grafts, which were autogenous inferior vena cava implanted in the thoracic aorta, revealed rupture of the nylon strands at the loops of the tulle weave This weave has a knotting of each fiber as it crosses another, in contrast to a taffeta weave, for example This knotting would be an advantage, we thought, in preventing slipping of the threads and in imparting maximal elasticity to the net It appears, however, that the nylon fiber "fatigued" at the knot with continuous pulsatile stress, and eventually broke It is significant that it was not until after two and a half years that we saw this, and emphasizes our contention that long term follow up is essential in vessel replacement programs

We supported aortic homografts in about 12 clinical cases but, fortunately, because of the size of the vessel, I generally used three or more layers of the net about the grafts In one patient with a single layer about an aneurysm which could not be removed because of renal arterial involvement, there was subsequent increase in size of the aortic aneurysm The patient died of rupture of the aorta well above the net, about sixteen months later

With regard to the use of synthetic materials for blood vessel replacement, we have had extensive experience at Presbyterian Hospital Following the pioneer work of Dr Blakemore's associates, my own laboratory group have joined forces in evaluating the various materials suitable for use as grafts Accordingly, over 130 dogs have been studied for up to four years There have been about 70 clinical replacements of aorta or peripheral arteries during the past two years by Drs Blakemore, McAllister, and myself A taffeta weave of Vinyon N, nylon, or Dacron has been employed, with very satisfactory results I must express a word of caution, however The ready accessibility of synthetic fibric from casual sources has encouraged surgeons to use these materials for vessel replacement, often with no technical information about the material and, unfortunately, at times without adequate technical background These fabrics should be obtained from reliable sources and have been well tested before clinical use Certain textiles used for clothing have dyes, toxic additives, and roughening processes employed in the finishing, that might make them unsafe for medical use The braided tubes are promising, but have not had an extensive nor long trial as vascular replacements For any of these synthetic materials to have good function, they must be used in the proper cases, and must be implanted with meticulous care

DR RICHARD H ADLER, Denver Colo —In answer to Dr Poppe's question, we have not found it necessary to use heparin postoperatively because the grafts have all remained patent Mural thrombi were found at post mortem examination of some grafts but these did not appear to progress and cause occlusion of the lumen The few grafts that had evidence of thrombi extending further were due to technical errors at the anastomoses Along this line, I should like to mention another material we are also using by itself, which is a type of 'calendered" nylon cloth As I understand this process of heat pressing, the microscopically demonstrable spaces between the fibers become relatively diminished I hesitate to mention this because the encouraging course of these grafts is only a little over six months old In dogs, we have replaced the entire descending thoracic aorta and are making aortic arches with satisfactory results Blood is let back into the graft which is surrounded by surgical sponges and manual pressure is exerted to counteract the blood pressure After one to three minutes, the sponges are removed and no bleeding occurs As a result, we have not found it necessary to use a method of thrombin coating or polythene sheet with this calendered nylon fabric to control leakage We have successfully used this material in one human patient to replace the aorta from below the renal arteries to both external iliacs I was interested in hearing Dr Deterling's comments about the two and three year follow up, and that again emphasizes the importance of long time follow up on these types of plastic materials before one can draw definite conclusions

THE LYMPHATIC DRAINAGE OF SILVER-COATED RADIOACTIVE GOLD COLLOID FOLLOWING INTRATHORACIC ADMINISTRATION TO PNEUMONECTOMIZED DOGS

R A Matuska, M D (by invitation), P F Hahn, Ph D (by invitation)
R I Carlson M D , S H Auerbach, M.D (by invitation), and
G R Meneely, M D (by invitation)
Nashville Tenn

There is no need to dwell upon the morbid statistics of bronchogenic carcinoma In an attempt to improve the results currently obtained by surgical and radiologic methods, investigation of the therapeutic value of radioactive isotopes has been carried out at the Nashville Veterans Administration Hospital Our interest was drawn to Au^{198} for 85 to 90 per cent of its energy is emitted as beta particles with a penetration of 0 3 mm (water) and thus evidence radiologic selectivity

Radioactive Au^{198} administered intrabronchially has been found in the regional mediastinal lymph nodes as has been previously reported from this laboratory[1] Unfortunately, Au^{198} with a half-life of 2 7 days moves slowly from its point of application and its energy has been largely expended by the time it appears in the regional lymph nodes

Hahn[2] has shown that radioactive colloidal Au^{198} treated with silver nitrate and ascorbic acid resulted in a preparation which retained the characteristics of gold from a radiologic standpoint but behaved as a silver colloid in the tissues with rapid absorption into the regional lymphatics and lymph nodes Hahn and Carothers[3] have shown that the intrabronchial administration of this silver coated gold results in an early appearance of the colloidal material in the mediastinal lymph nodes in a significant quantity

This paper reports the results of silver-coated gold introduced into the empty hemithorax of dogs following pneumonectomy

Mongrel dogs, 10 5 to 19 5 kilograms in weight, were subjected to pneumonectomy At various times during the postoperative period silver-coated gold colloid was injected into the empty hemithorax the dosage ranging from 11 to 150 mc The dogs were sacrificed at various intervals postinjection ranging from two to forty-four days There was one death in this series Dog No 18 died on the thirty first day after injection from pneumonia which was felt to be unrelated to the therapy

At autopsy representative lymph nodes were dissected out cleansed of adventitial tissue weighed placed in formaldehyde and the radioactivity deter-

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From the Research Laboratory, the Radioisotope Unit, Thayer V A Hospital, The Cancer Research Laboratories and the Departments of Surgery, Pathology and Medicine, Vanderbilt University School of Medicine, Nashville, Tenn

Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery, Atlantic City, N J, April [illegible] mined in a Texas well counter. Histologic studies were done. The following nodes were studied: right bronchial, carinal, left bronchial, anterior superior mediastinal, right superior mediastinal, left superior mediastinal, right supraclavicular and left supraclavicular. These are illustrated in Fig. 1.

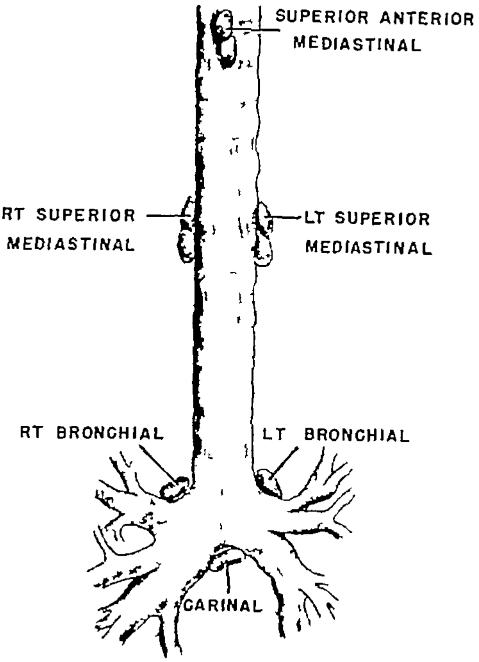

Fig. 1.

In addition, specimens of the parietal pleura, the pericardium, the liver, and spleen were studied. Gross inspection of the hemithorax at autopsy showed no evidence of inflammation. Bronchial stumps healed well in all cases. Histologic study of the liver, spleen, and, in 1 case, the bone marrow showed no abnormalities.

RESULTS

Significant quantities of the colloid material were found in the mediastinal nodes in dogs sacrificed on the second day. Dogs sacrificed later did not have significantly more gold in the nodes studied. In calculating the beta equivalent roentgens, only the radiation emitted after forty-eight hours was determined. In all dogs studied, the mediastinal nodes received the greatest amount of irradiation, only a rare hilar node received significant amounts. The length of time between operation and injection of the isotope did not seem to alter the results. For convenience the dogs can be divided into two groups.

Group I consists of dogs that received a dose of 40 mc or more. There were 10 dogs in this group (Table I). It will be noted that in this group the anterior superior mediastinal nodes received adequate irradiation in all instances and the right superior mediastinal and left superior mediastinal nodes in about 70 per cent of the cases In Dogs No 18 and No 19 a long interval existed between injection and counting Counts on these dogs, due to the rapid decay curve of gold, were too near the background count to permit calculation of the radiologic effect However histologic studies showed these nodes to be markedly disorganized If these are considered as having received adequate irradiation the percentage is then 90 per cent

TABLE I GROUP I, DOGS RECEIVING 40 MC OR MORE

NUMBER	DOSAGE	β SUPERIOR ANTERIOR MEDIASTINAL	β SUPERIOR MEDIASTINAL LEFT	β SUPERIOR MEDIASTINAL RIGHT
26	44 4 mc	28,546	5 855	13,270
27	44 4 mc	199 254	181 032	315,675
14	50 0 mc.	6,211	96	85
12	50 9 mc	88,632	3 451	2,096
8	52 0 mc	198 077	9 869	48 735
9	52 0 mc	83,220	52 440	96,777
10	52 0 mc	34 940	16,783	Lost
18	75 0 mc	150 314	Count too near background	Count too near background
19	75 0 mc	365 489	Count too near background	Count too near background
28	150 0 mc	94 620	86 549	181 716

Group II consists of 11 dogs that received less than 40 mc (Table II) This table shows the beta equivalent roentgens received in the three groups of mediastinal lymph nodes in these dogs With this smaller dosage results were less predictable Even with these doses the anterior superior mediastinal nodes received therapeutic irradiation in about 40 per cent of the cases

TABLE II GROUP II, DOGS RECEIVING LESS THAN 40 MC

NUMBER	DOSAGE	β SUPERIOR ANTERIOR MEDIASTINAL	β SUPERIOR MEDIASTINAL LEFT	β SUPERIOR MEDIASTINAL RIGHT
4	11 0 mc	17	14 963	3
5	11 0 mc	3 419	2 637	27
6	11 0 mc.	8 245	Lost	4,120
29	12 0 mc	Lost	19 228	2 518
24	13 6 mc	147	6 474	2 598
25	13 6 mc	3 878	11 509	6 236
32	15 0 mc	31 372	1 294	711
33	15 0 mc	78 295	746	149
35	15 0 mc	184 244	59	413
15	22 0 mc	2 757	100	770
16	32 0 mc	2 766	20 200	10,200

Microscopic study of the mediastinal nodes showed destructive changes which were roughly but not constantly proportional to dosage and elapsed time In the most severe form there was total necrosis of the nodes and the immediately surrounding tissues including blood vessels large enough so that the smooth muscular layer could be identified (Fig 2) In the less severe forms the nodal architecture was partially preserved but there was more or less complete loss of lymphocytes plasma cells and reticulum cells were prominent survivors in these nodes (Fig 3) Evidence of regeneration of lymphoid tissue was observed in some long-term survivors Erythrophagocytosis was a prominent feature in nodes with high counts from animals sacrificed early and also in some with moderately high counts sacrificed later

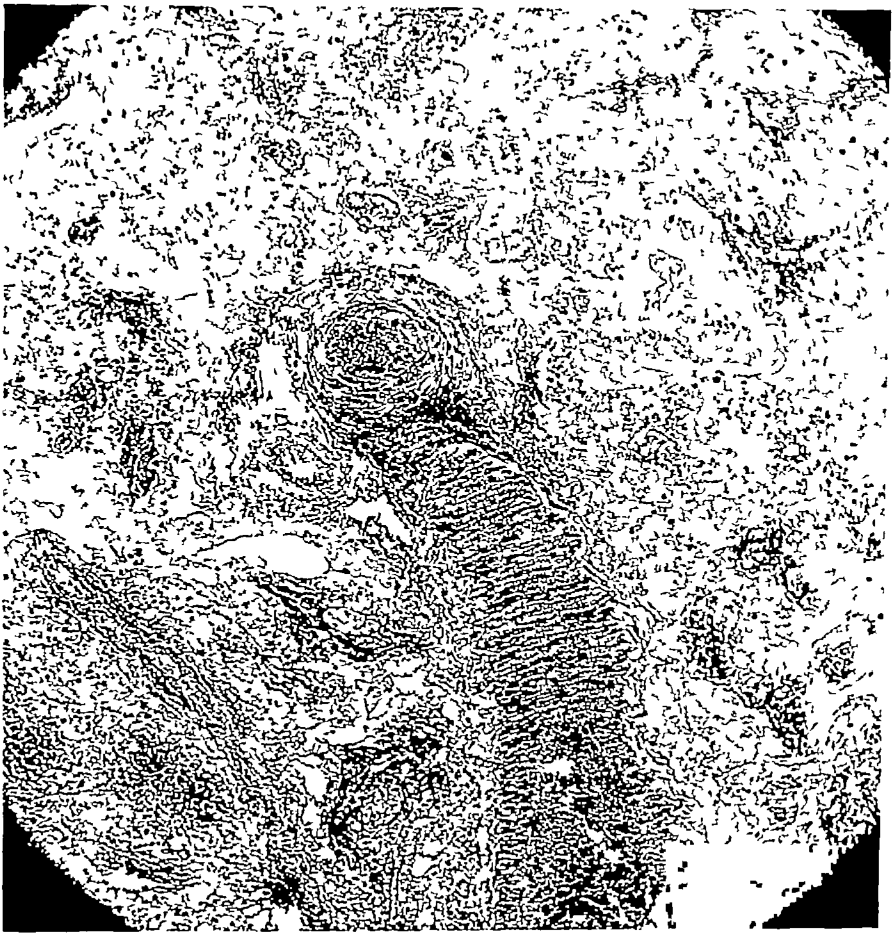

Fig 2

DISCUSSION

One can conclude from this experiment that the parietal and mediastinal pleurae in pneumonectomized dogs drain into the mediastinal nodes and that in normal dogs these nodes may be destroyed by the intrapleural injection of radioactive silver coated gold colloid solution

It is unlikely that lymph nodes replaced by tumor would pick up sufficient radioactive material to sterilize them It is not unreasonable, however, to believe that small emboli in these lymph nodes could be destroyed by this method One of the great advantages of this form of treatment is the easy manner with which it may be used as an adjunct to surgery

If these observations prove to be valid in the human being, a prophylactic type of mediastinal dissection could be added to pneumonectomy in the treatment of patients with resectible bronchogenic carcinoma

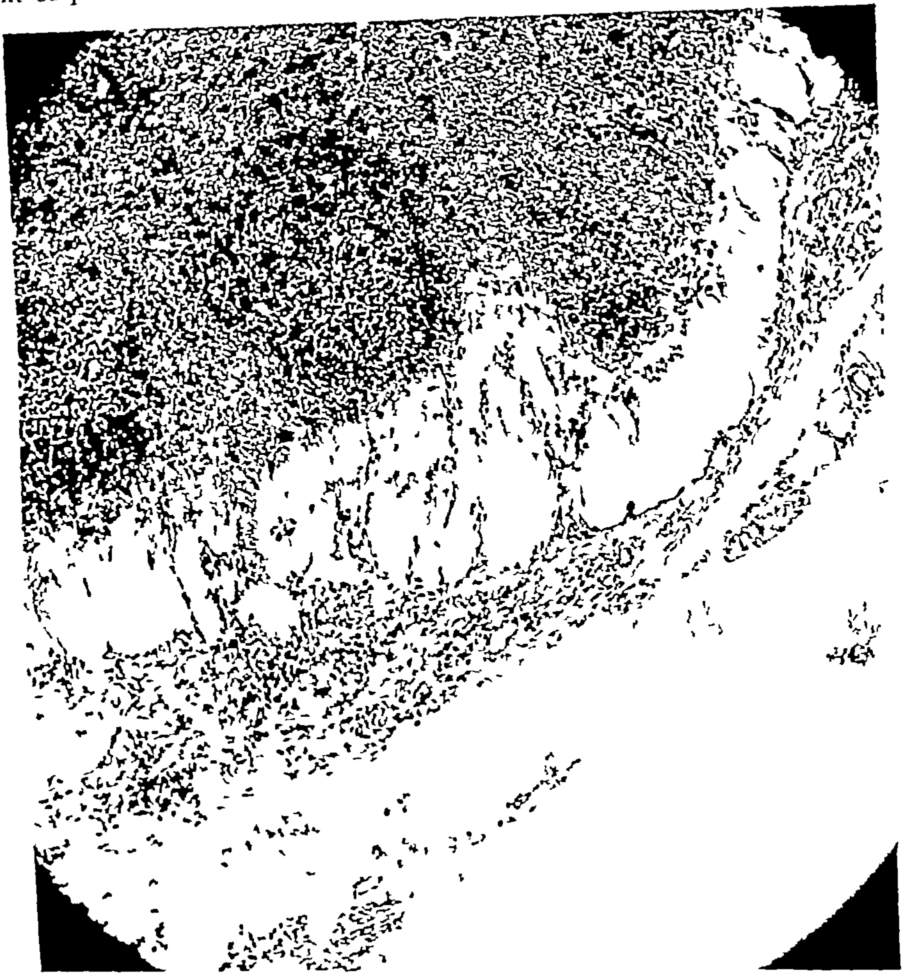

Fig 3

Currently at the Nashville Veterans Administration Hospital, silver coated radioactive gold colloid is being injected into the empty hemithorax of patients who have had pneumonectomy for bronchogenic carcinoma The dosage has ranged from 75 to 150 mc It is much too early to analyze the results of this procedure however to date no ill effects have been observed

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DISCUSSION

DR REX PERKINS, Birmingham, Ala —We have done animal work of a similar nature, and our findings agree with those that Dr Carlson has so well presented The bronchial stump healed well in the presence of heavy doses of radioactive Au^{198} despite the fact that we encouraged disruption by leaving the stump long, using heavy silk, and not pleuralizing the stump The gold is taken up by hilar and mediastinal nodes, as demonstrated by tissue count and radioautographs We were unable to correlate closely the size and duration of dose with tissue counts and radioautograph picture We are at present continuing this work in an effort to quantitate nodal uptake more closely

As we know, certain dyes injected near a cancer tend, by lymphatic spread, to circumvent the cancerous nodes and go to normal nodes This may also happen in the situation we are considering with Au^{198} Nevertheless, since the procedure is safe, and since the Au^{198} is taken up by mediastinal nodes, including those of the opposite side, in quantity sufficient to destroy the nodes, we feel that this procedure deserves an extensive controlled clinical application

CIRCUMFERENTIAL SUTURE OF THE MITRAL RING

A Method for the Surgical Correction of Mitral Insufficiency

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Robert G. Trout, M.D. (by invitation), Frank S. Mansure, M.D. (by
invitation), Newell E. Wood, M.D. (by invitation), O. Henry Janton, M.D.
(by invitation), and Bart D. Iaia, Lieutenant Commander (MC), USNR
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THE concept for reducing the size of the annulus in valvular insufficiencies as a method for the correction of this dysfunction has been presented in previous publications.[1, 2] Compared to the principle of replacement of occluding valvular elements upon which practically all previously suggested techniques are based,[3-12] the reduction of the valvular ring by circumferential suture has several theoretical and practical advantages. This is especially true when applied to the atrioventricular valves, more specifically the mitral valve. These advantages include the fact that this procedure does not require the introduction of foreign materials across the lumen of the cardiac chambers. It makes full use of all remaining valvular substance capable of function. The effective orifice of the atrioventricular communication is not encroached upon by plugs or sutured cusps. It involves no more intracardiac manipulation than does a commissurotomy and results in no significant myocardial trauma. It not only makes possible the elimination or reduction of regurgitation, as will be shown, but it is plausible to expect that the size of the atrioventricular ring will be rendered incapable of progressive enlargement. This principle, with or without concomitant commissurotomy, appears applicable to most forms of mitral insufficiency.

Three of the foregoing statements merit further clarification. Techniques involving the use of prosthetic plugs or leaflet suturing methods are associated with considerable operative trauma and with unavoidable reduction in the capacity of the effective valvular orifice. The placement of any known material across the lumen of the vascular chambers has long been known to result in a very high incidence of thrombosis frequently giving rise to embolization. Tissue grafts which are subjected to the pressures extant in the heart chambers (particularly the ventricles) will initially swell and present a serious danger of obstruction. These tissues ultimately fibrose and shrink completely losing their flexibility.[3, 4] A surgical procedure which can achieve the desired result

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Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery, Atlantic City, N. J., April 24 to 26, 19

From The Cardiovascular Research Laboratories, the Department of Thoracic and Cardiac Surgery, and the Department of Medical Cardiology at the Presbyterian Hospital in Philadelphia.

This work was aided by a grant from the Schuylkill County Chapter of The American Heart Association, by the U. S. Public Health Service Grant No. H-1[illegible] (C), by the Cardiovascular Research Fund of the Presbyterian Hospital, and by The Cardiovascular Research Foundation of America.

without the use of intracardiac foreign materials and without impeding blood flow would seem to be, physiologically and anatomically, a more acceptable approach to the problem of mitral regurgitation In a sense, the circumferential suture procedure can be compared to techniques used in stenotic valvular disease in which the success attained is, in great measure, due to the fact that these techniques necessitate intracardiac manipulation only and do not otherwise alter the structures involved

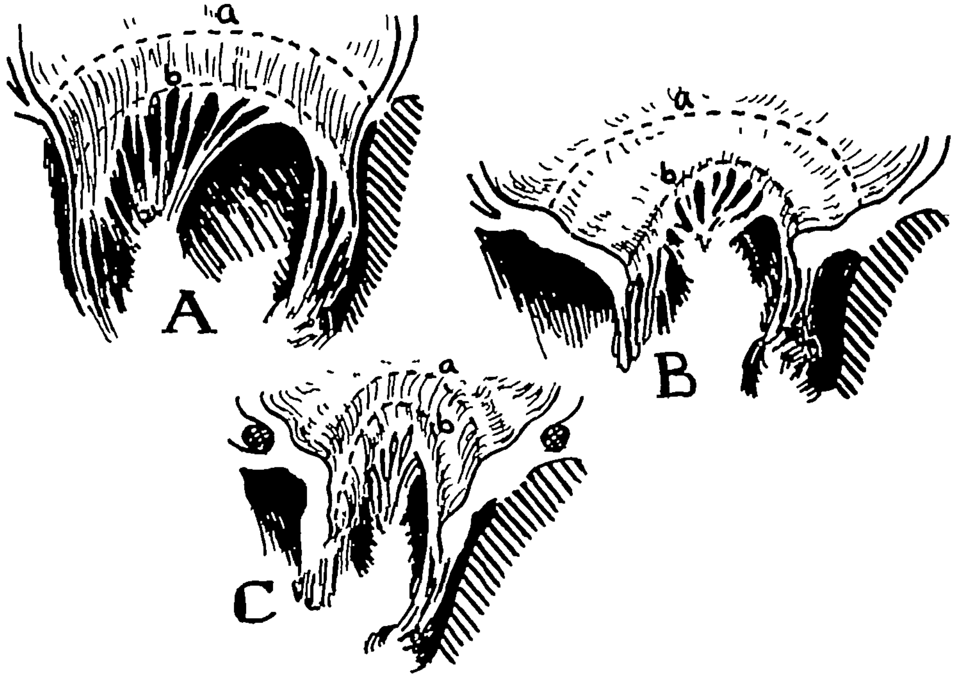

Fig 1 —A semidiagrammatic representation of the *A*, Normal mitral valve ring and leaflets in diastole.

B, Diseased mitral valve in which marked insufficiency with enlargement of the ring is present. This figure attempts to show the discrepancy between the potential (a) and effective (b) orifices

C, Represents the circumferentially constricted A V ring illustrating the relaxation of the leaflets and the freedom of the effective orifice (See text.)

The anatomy of the mitral valve utilizes the basic construction principles of simple, unidirectional mechanical valves The flow through such valves depends upon the size of the orifice opened when the occluding elements retract This can be termed the *effective orifice* The efficiency of the valve depends not only on its ability to open and provide minimum resistance to diastolic flow but also on its capacity completely to occlude the communication between the chambers involved during systole This communication can be termed the *potential orifice* because it is that which would result if one were to remove or destroy all valvular substance In the normal mitral valve (as well as in the tricuspid), the retractility of the leaflets provides an opening (the effective orifice) which almost equals in total area that encompassed by the annulus and ventricular inflow tract (the potential orifice) In the diseased valve, however, commissural fusion, leaflet thickening and rigidity, shortening of chordae tendineae and enlargement of the annulus, all tend to increase the discrepancy between the effective and potential orifices. Circumferential suture of the regurgitant atrioventricular valves is logical because reduction of the area of the potential orifice can thereby be accomplished without significant encroachment upon the effective orifice. This is so because of the pathologic morphology of the valve as there is usually a substantial amount of potentially functional valvular tissue between the two orifices (Fig 1)

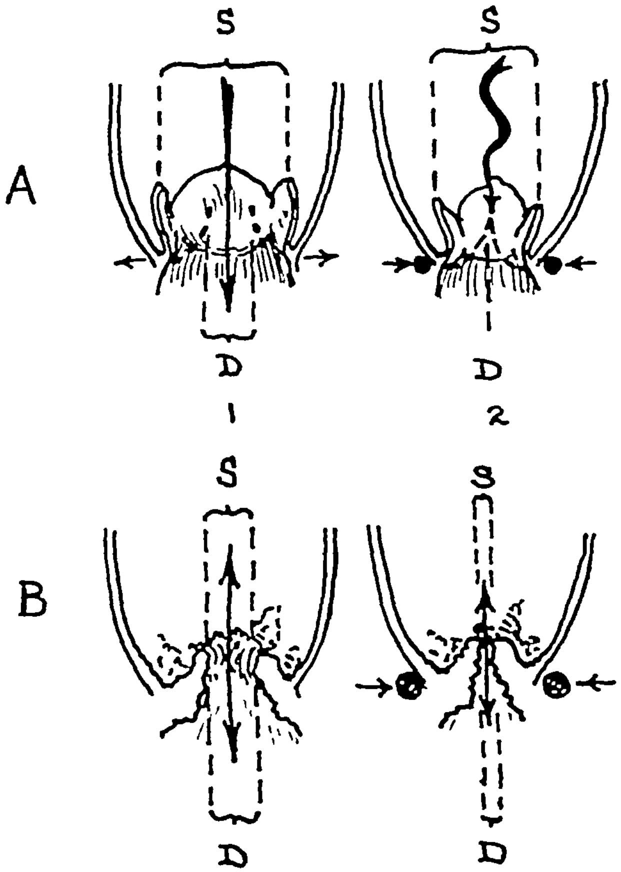

Fig 2 — A Illustrates the situation in syphilitic aortic insufficiency where a dilatation of the valvular ring plays a prominent role (1) Conceivably constriction of the annulus (2) could eliminate insufficiency without producing stenosis because the cusps remain pliable and are able to function reasonably well

B Represents the contrasting situation in nonsyphilitic aortic valve disease where the insufficiency is associated with fixed rigid cusps incapable of motion (1) Constriction of such a valve ring (2) would seem to be inevitably associated with an aggravation of stenosis in any proportion to the relief of insufficiency (S, systole; D, diastole)

In certain types of regurgitation of the ventricular outflow valves (i e, syphilitic aortic and relative pulmonic insufficiencies), it is quite conceivable that circumferential constriction may reduce the discrepancy between the corresponding effective and potential orifices without significantly embarrassing forward flow On the other hand in those conditions in which aortic insufficiency is associated with extensive scarring, calcification and fixation of the cusps, it appears doubtful that the principle of annular constriction can be applied for the reduction of regurgitation without producing serious degrees of stenosis This is true because pathologically there is a rigid continuity of the cusps with the ring upon which they are supported (Fig 2) In such cases, there is not the residual pliability that one finds in the diseased mitral valve

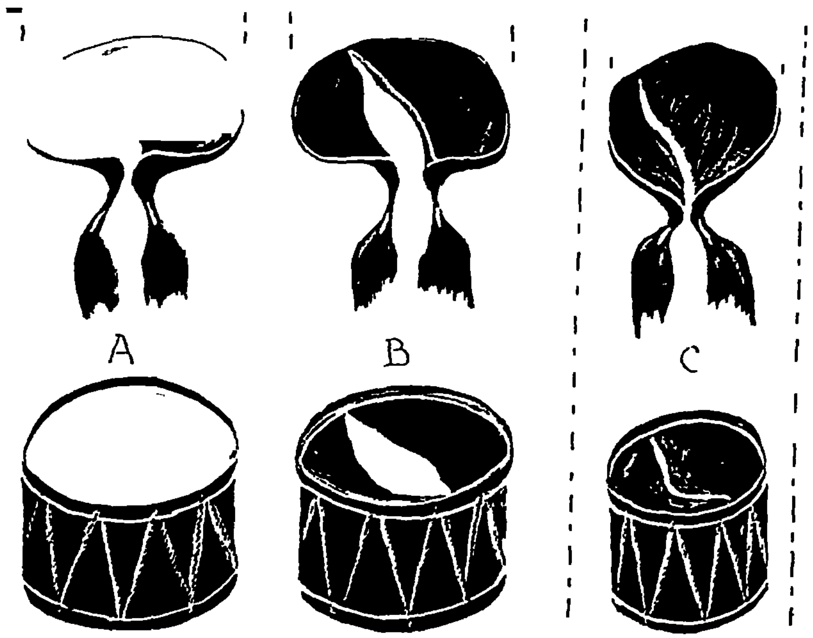

Fig 3 —*A* In a diseased mitral valve which is both stenotic and insufficient the leaflets are under tension in a manner similar to a stretched drumskin.

B If a commissurotomy is performed stenosis should be relieved but serious regurgitation frequently results as a consequence of the separation of the cusps This is comparable to the gap which results if one slashes a taut drumskin

C If the annulus is reduced in size the leaflets can relax and can be enabled to come in contact with each other *This is comparable to mounting the slashed drumskin from a large drum on one of smaller diameter*

It has been noted that in a large number of mitral valves in which there is a combination of stenosis and insufficiency there is, also, a significant degree of annular dilatation which places the leaflets under severe tension and further hampers their ability to move (Fig 3) Edwards[16] has described a phenomenon comparable to a sliding herniation in which the annulus is displaced upward (toward the atrium) in cases of severe mitral insufficiency

It should be understood, then, that the efficacy of the procedure herein presented depends directly upon the degree of valvular mobility or residual potential function found in any given instance Its mechanical limitations, therefore, appear to be similar to those of mitral commissurotomy If one should be confronted with an incompetent but solidly calcified, rigid, unyielding valve, such as those which when stenotic, respond but poorly to commissurotomy, the result of circumferential suture might likewise be unsatisfactory Fortunately such cases are in the minority. In such situations nothing short of actual valve replacement will suffice. Until such a feat is possible, however, in serious degrees of surgically produced or existing insufficiency in association with such a valve, one may speculate that placement of a circumferential suture might be of value if only to fix or stabilize the size of the ring, even though the initial degree of regurgitation be but slightly reduced or remain unchanged.

Based on the arguments just presented and after a study of the pertinent anatomic features in normal and diseased human valves, an experimental program was initiated to investigate the problems associated with the correction of valvular insufficiencies by the circumferential constriction of the annulus. To date this work has involved experimentation on some 150 dogs. In the course of these studies a well grounded technique for the correction of mitral insufficiency has been evolved. This communication deals with the study of 80 animals in which this procedure was performed. The technique as used here is the result of modifications of various approaches tried in preliminary experiments. The results of the initial clinical trials are also included.

EXPERIMENTAL WORK

In a series of eighteen acute experiments,[1-15] mitral insufficiency was produced by either tying the mural (posterior) leaflet to the heart wall or by lacerating this leaflet with a hooked knife. The resulting regurgitation was then corrected by placing a circumferential suture around the annulus. In every case an excellent regurgitant jet was palpable to the intra-atrial finger. A gross thrill was evident on the surface of the atrium and the typical changes of insufficiency were recorded in pressure pulse tracings. In each instance the regurgitation was either completely eliminated or reduced to practically undetectable degrees (Figs. 4 and 5). To accomplish this it was necessary to constrict the mitral ring to a diameter which was never less than 2.3 cm. (4.1 sq. cm.) in the 9 dogs in which regurgitation was produced by tying the leaflet. The diameter of the constricted ring in 8 of the 9 dogs in which the cusp was lacerated was never less than 1.8 *cm.* (2.5 *sq. cm.*). In the ninth animal constriction had to be carried to a ring diameter of 1.4 cm. (1.5 sq. cm.). These subjects were sacrificed in order to check the placement of the suture and to determine the extent of valvular immobilization or laceration as well as the degree of constriction.

A study of the circumferential suture technique and its possible consequences was carried out in a separate series of 62 dogs ranging in size from 25 to 60 pounds. These healthy adult mongrel dogs were anesthetized with pentobarbital sodium (15 to 30 mg. per kilogram of weight) and ventilated by connecting a Pneophore* or a homemade circular valve type of respirator to a rigid endotracheal cannula equipped with a pneumatic cuff. Electrocardiograms were made on the anesthetized animals before surgery, recording the standard and unipolar limb leads as well as the usual six chest leads. In the first 28 animals a clean technique was followed. In the remainder strict asepsis was observed

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*Mine Safety Appliances Co., Pittsburgh, Pa.

Technique —The left chest was entered through the sixth interspace and the pericardium opened after mobilizing the phrenic nerve A hemostatic purse-string suture was placed about the base of the left atrial appendage Pressure tracings were then taken singly in the left atrium, left ventricle, aorta, and pulmonary artery The circumferential suture was placed and the series of tracings was repeated before tying the suture, five minutes after it was tied to 1 8 to 2 0 cm in diameter, and again twenty minutes after tying the suture The measurement of the constriction was determined by measuring the operator's left index finger and constricting the ring around a predetermined point on this finger The pericardium was closed in all animals in which no pericardial bolster was used (described later) and left open in the others The lungs were inflated and the chest was closed with wire The electrocardiogram

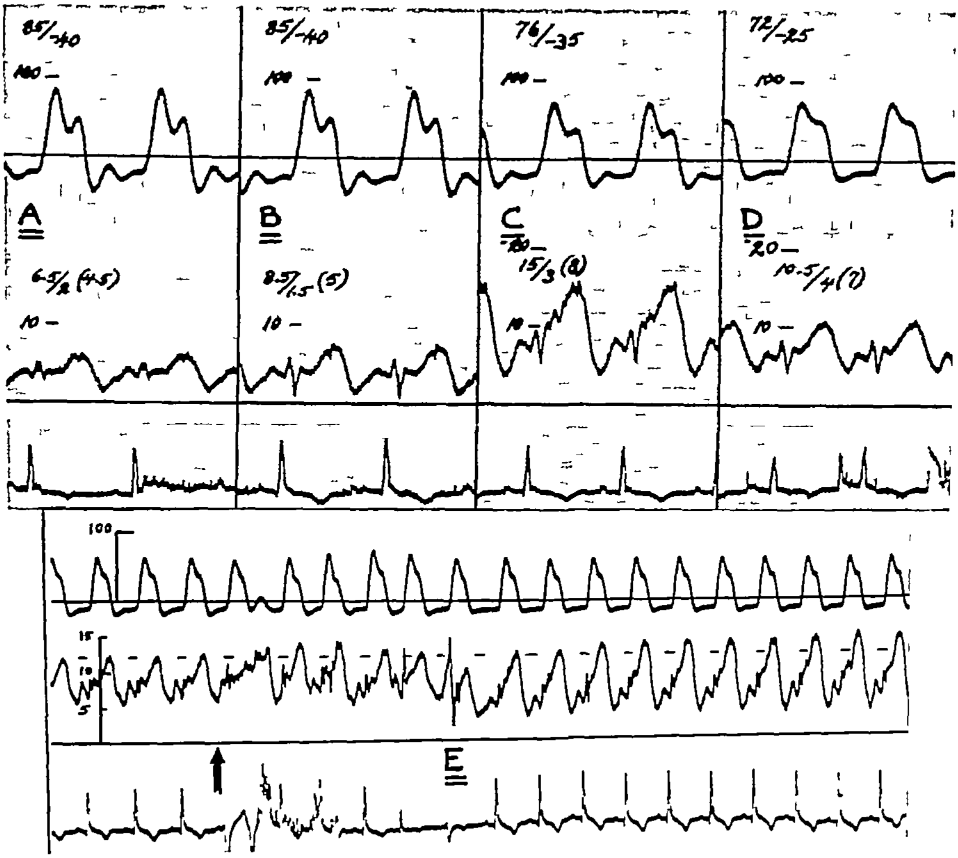

Fig 4 —*A* Pressure tracings taken in a dog after exposure of the heart *B* After placement, but before tying the circumferential suture the same tracings were taken *C* This was repeated after production of mitral regurgitation by lacerating the mural leaflet. *D* Tracing taken after tying of the suture to a ring diameter of 1 8 cm

Upper tracing left ventricle middle left atrium lower ECG Lead II Note the reversal of both pressure and contour of the tracings after the suture was tied

E, Same experiment. To the left of the arrow is the tracing obtained after correction of the regurgitation While a continuous recording was made the circumferential suture was cut and pulled out (at arrow) Note that after this point the regurgitant contour and pressure changes reappear

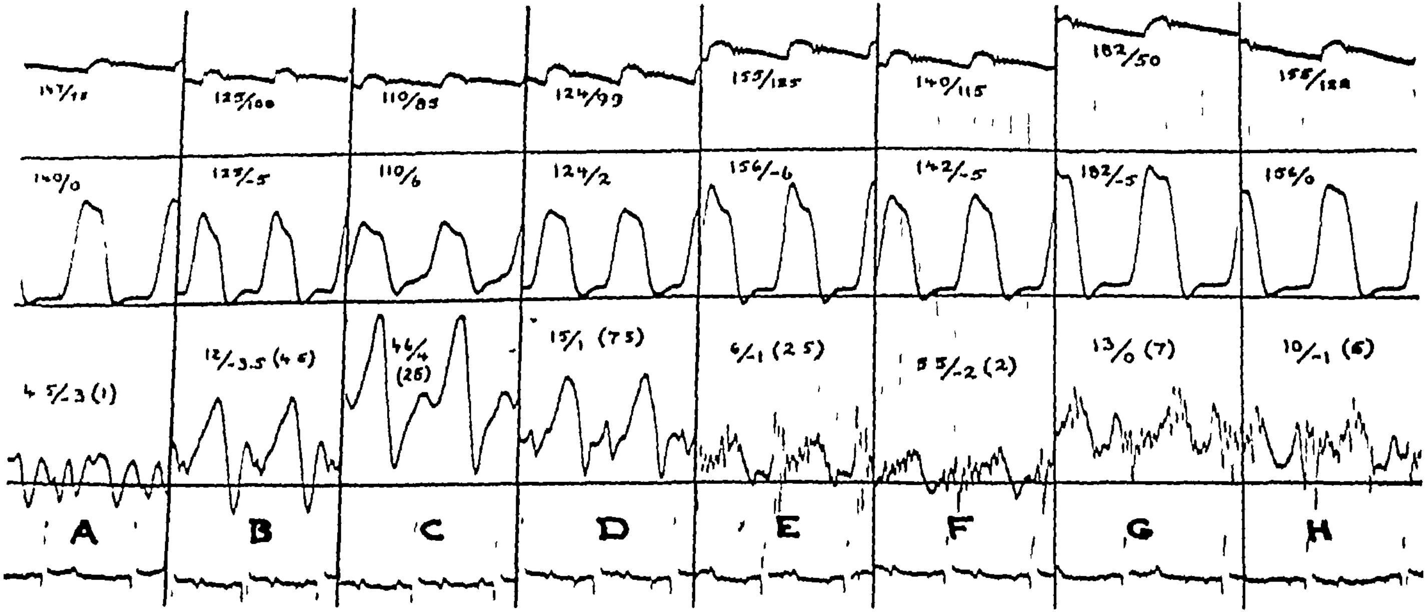

Fig. [illegible].—An experiment in which: A, An initial set of pressure pulses was recorded. From above downward are the aortic, left ventricular, left atrial, and ECG Lead II tracings. B, Mitral regurgitation was produced by lacerating the mural leaflet. C, Methoxamine (0.5 mg.) given intra-arterially. Note the enormous rise in left atrial pressure and the exaggeration of the regurgitant contour. Note also the failure of the left ventricular and aortic pressures to rise. D, Ten minutes after the administration of Methoxamine the left atrial pressure drops to a level close to that seen in B. E, The circumferential suture was now tied to 2.0 cm. Note the immediate changes in pressure and contour. Note also the increased amplitude of the vibrations of valvular closure (c wave) in the left atrial record. The aortic and left ventricular pressures rise. F, The recording repeated ten minutes after the suture was tied showing a further drop in atrial pressure. G, At twenty minutes after the initial dose of Methoxamine (C) a second equal dose was given but now the circumferential suture had been tied. Note the marked rise in ventricular and aortic pressures but the relatively little elevation in left atrial pressure as compared with that seen in C when the mitral insufficiency was uncorrected. H, Ten minutes after G the tracings were repeated showing a gradual return to normal pressure levels as the effect of the vasopressor wears off.

was repeated at the completion of the operation. The survivors in this series were reoperated upon at one- to six-month intervals. At that time a preoperative electrocardiogram was again made, the chest was opened to expose the heart and a series of pressure tracings was made as before. The animals were then sacrificed for examination of the heart, lungs, liver, spleen, and kidneys, routinely, and of the brain when a lesion was suspected. All hearts were preserved in Formalin and paraffin histologic sections made of cuts from selected points on the mitral ring and myocardium as well as of other organs which might have been grossly suspected of pathology.

The suture material used in 21 dogs was No. 2 braided silk of three different brands.* In 13 animals, braided cotton umbilical tape was used.† In the subsequent 28 animals, the same cotton tape was placed but in addition a segment of it was covered with a sleeve or bolster of pericardium.

In the first 34 animals, the technique consisted of placing the suture medially by starting for the posterior aspect of the heart at a point just to the left of the posterior descending coronary artery and immediately beneath the coronary sinus and distal circumflex coronary artery. The needle (a large Reverdin, after trial of several types, proved to be preferable) was passed ventrad in the base of the interatrial septum, emerging in the transverse sinus at the junction of the anterior atrial walls with the septum. The posterior tail of the suture was then threaded on a large, curved needle (Mayo or Ferguson type) and stitched anterolaterally into the atrioventricular groove, underpassing the lateral branches of the circumflex coronary so that it finally lay just beneath the circumflex bundle. The anterior tail of the suture was then stitched beneath the circumflex coronary artery and great cardiac vein at a point about 5 to 10 mm. from the take-off of the anterior descending coronary. The two tails were thus brought together a few millimeters to the left of the anterior descending coronary and immediately below the circumflex coronary in the periannular fat pad. At this point they were tied in a double square knot.

In the later 28 animals, the technique was modified in that no attempt was made to keep the medial segment of the suture within the substance of the septum. This portion of the suture was intentionally passed into the right atrium, entering this chamber at a point just ventrad to the ostium of the coronary sinus, then passed adjacent to the right side of the septum, piercing the anterior right atrial wall at its junction with the anterior base of the septum. At this point the suture emerged into the transverse sinus as before. The segment of suture which was to lie in the transverse sinus was then encased in a pericardial sleeve 4 cm. in length. In 8 dogs, this sleeve was left attached as a pedicle graft. In the others, it was detached as a free graft. A tunnel was made anteriorly beneath the circumflex coronary and great cardiac vein at a point about 1 cm. lateral to the anterior descending coronary. This segment of the suture so bolstered was then drawn back into the transverse sinus by traction on the posterior tail. The anterior tail was passed beneath the circumflex through the previously constructed tunnel. In this manner, the pericardium-covered portion of the suture lay in the groove of the transverse sinus extending from the anterior walls of the atria through the tunnel and emerging anteriorly just beneath the circumflex coronary. The posterior tail was next carried anterolaterally underpassing the coronary branches and tied anteriorly as before (Fig. 6).

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*Davis & Geck Anacap, Ethicon and Deknatel black braided silk swaged on 6 inch semimalleable needles made up at our request.

†Gudebrod Brothers braided umbilical tape.

The reason for the modifications in the technique used in this last group of dogs, especially the use of pericardial bolsters, was the fact that in two thirds of the animals surviving the placement of either the braided silk or the bare

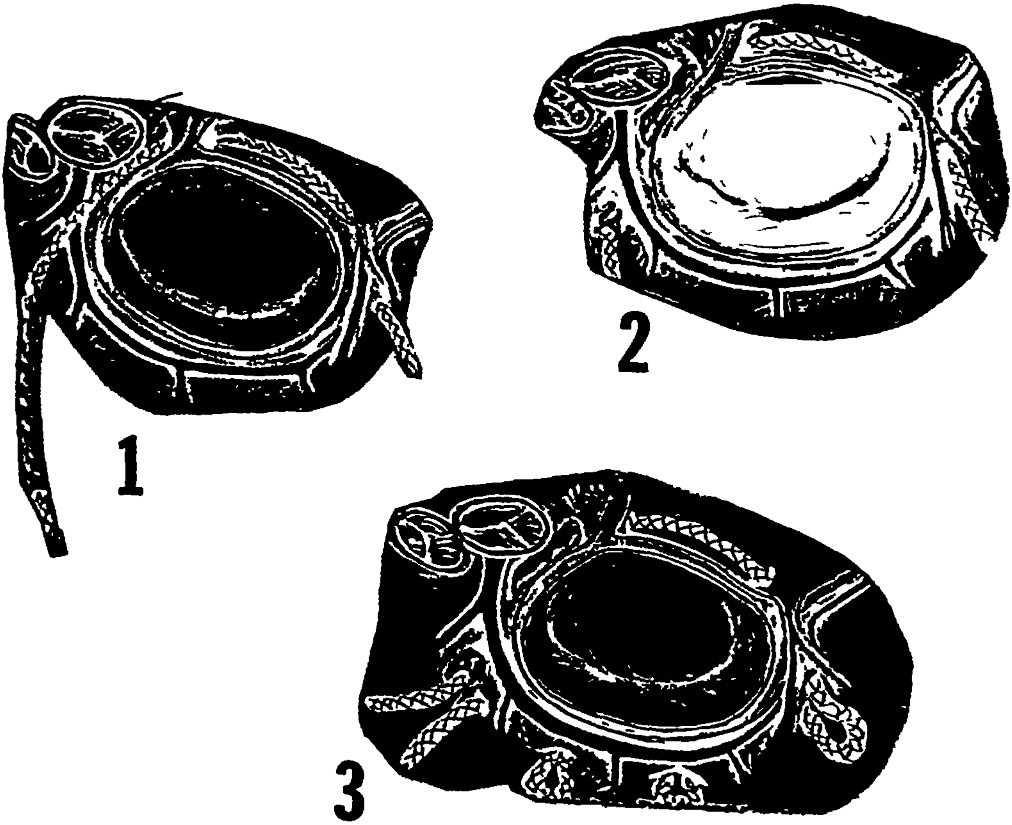

Fig. 6.—1. The initial segment of the circumferential suture placed. A segment of the anterior tail has been wrapped in a pericardial sleeve.
2. The suture has been pulled back drawing the pericardium-covered portion into the transverse sinus. The anterior tail has been passed beneath the circumflex coronary artery through the previously dissected tunnel.
3. The posterior tail has been stitched laterally and anteriorly into the atrioventricular groove to complete the final segment of the ring.

nylon tape the suture cut through the tissues eroding into the lumen of the left atrium. It was found that this erosion occurred consistently in precisely the same area, namely, that segment of the ring adjacent to the transverse sinus. The mechanism of this erosion was comparable to that of a string cutting its way through a cake of ice. That is to say, as the suture cut its way inward its

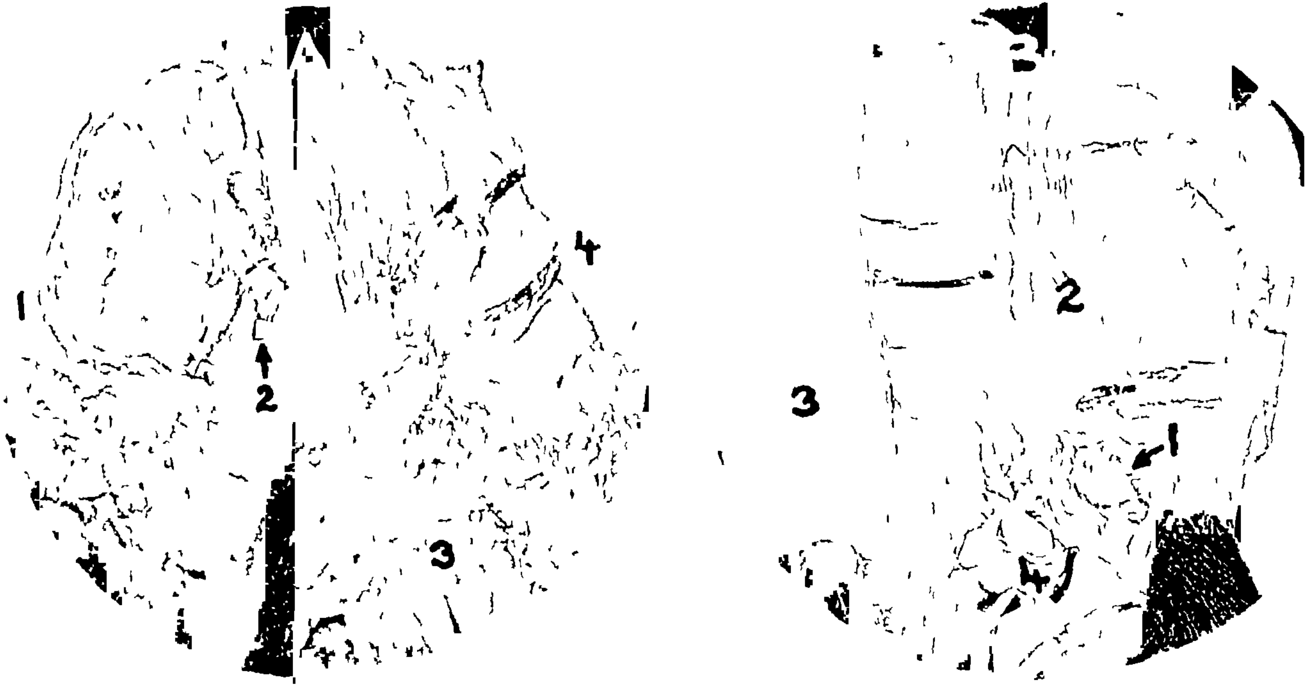

Fig. 7.—A, (1) Right atrial surface of the interatrial septal base showing the endothelialization and fibrosis which cover the cotton tape (2). 3, Rim of the interventricular septum. 4, Lumen of the left atrium. (Microphotograph of 1 month specimen. Hematoxylin & eosin ×10.)

B, Section showing the cotton tape (1) buried in the interatrial septum (2). 3, Left atrial lumen. 4, Interventricular septal rim. The right atrial lumen is on the right side of the illustration. (Microphotograph of 2 month specimen. Hematoxylin & eosin ×10.)

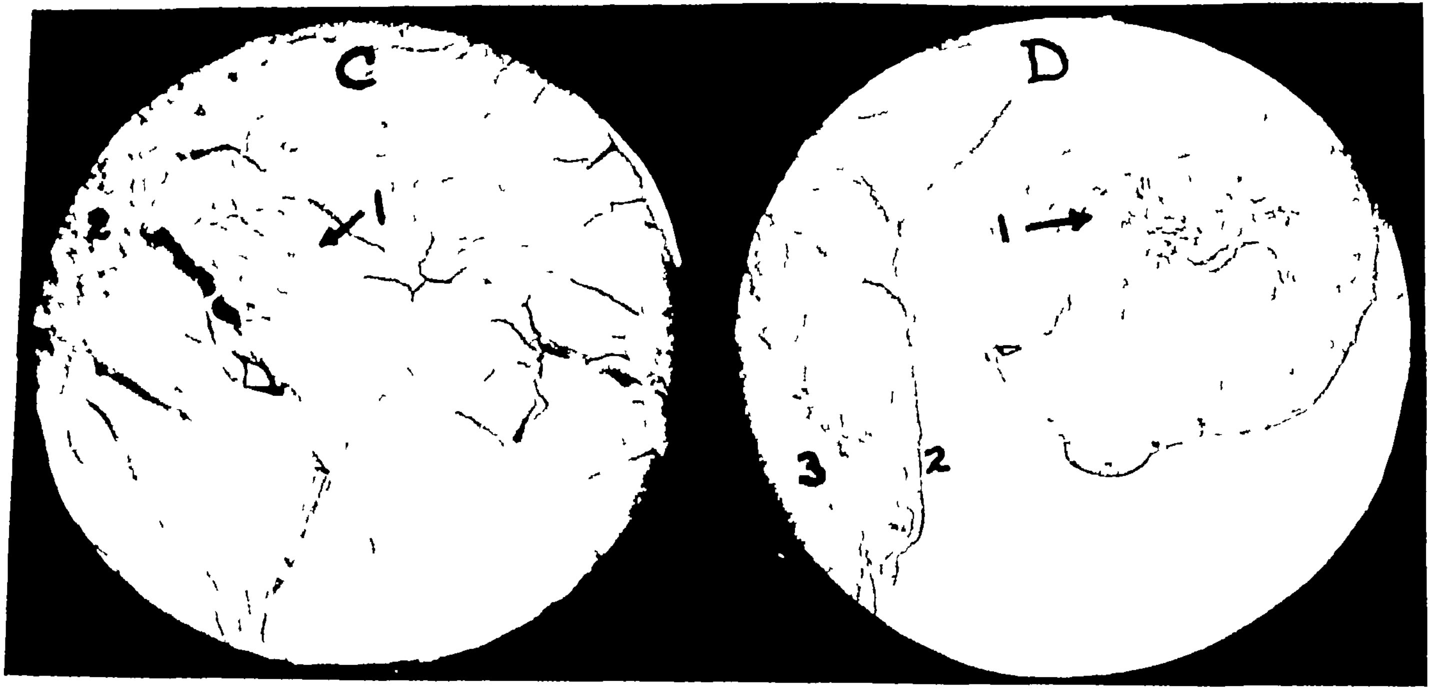

Fig. 7 (Cont'd).—C. The cotton tape was placed into the myocardium where it becomes encased by a fibrous envelope (1) and surrounded by healthy heart muscle. 2, Areolar and fatty tissue of the peri-annular fat pad. (Microphotograph of 5 month specimen. Hematoxylin & eosin ×10.)

D. Section through the shelf taken to show the shelf formation (1), the suture (silk) (2), the base of the mitral leaflet and (3) a portion of ventricular myocardium. (Microphotograph of 6 month specimen. Hematoxylin & eosin ×10.)

path healed behind it This resulted in the formation of a curious shelflike projection of fibrous tissue into the lumen of the atrium This shelf was consistently located a millimeter or two above the valve ring, extending from the anterior limits of the interatrial septum to a point just lateral to the anterolateral commissure, forming a crescent-shaped scar In most of the specimens, the suture presented in the center of the crescent so that a small portion of it lay exposed to the blood stream Here, a polyplike mass of granulation tissue, varying in size from 2 mm to 1 cm was almost always present (Fig 7, *A*, *B*, *C*, *D*, and *E*) In 2 animals, erosion was so rapid that an acute, fatal cardiac tamponade resulted

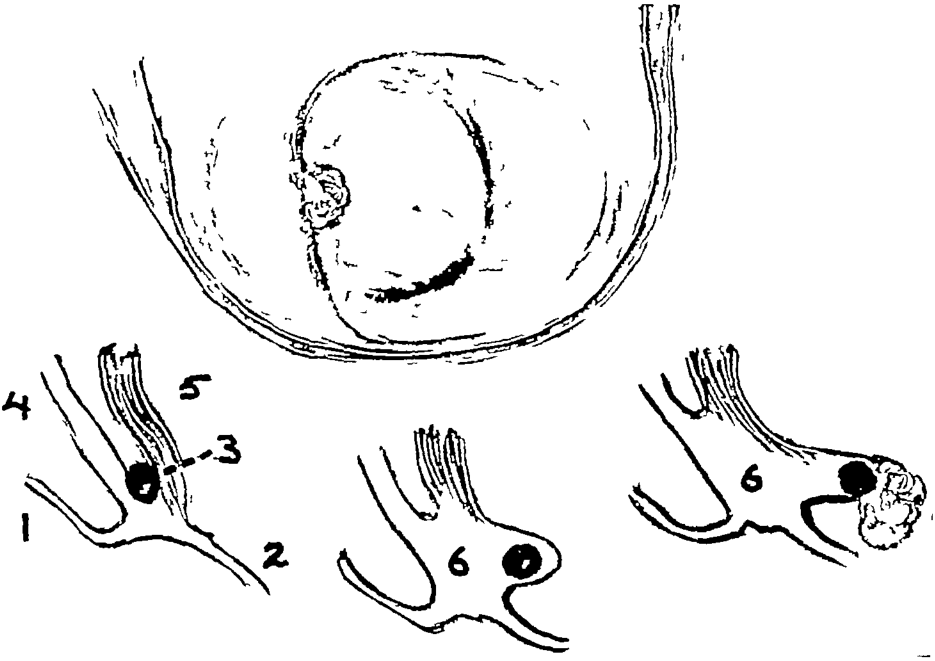

Fig 7 (Cont d) —*E*, The diagram at the top of the illustration demonstrates the appearance of the crescent-like scar or shelf' with its central polyplike mass of granulation tissue as viewed from the atrial side. Below this diagram are three sections across the segment of the ring which is adjacent to the transverse sinus to show the position of the suture in the groove of the sinus and then as it gradually erodes into the atrial lumen *1* aortic valve cusp *2*, mitral valve cusp *3* suture *4*, aortic wall *5*, atrial wall *6*, scarring in the path of erosion and obliteration of the transverse sinus groove.

Since the observation was made that the site of erosion was always the same, it was reasoned that this was probably due to the fixation of the annulus at this point to the fibrous framework that supports the tricuspid and aortic rings as well as the mitral, to the thinness of the left atrial wall at the base of the appendage, and to the "sawing" action of the suture Means for preventing this were considered Among these, the possible use of other suture materials was prominent It was thought that a smoother, softer, and larger caliber material might be in order Tissue strips were thought to be too unreliable since the likelihood of their uncontrollable constricting effect by scarring presented a potential danger of producing too great a narrowing of the ring While investigating the possibility of obtaining a more suitable material it was thought worth while to try covering the offending segment of suture with a pericardial sleeve or bolster Because of its segmental application this tissue cover seemed unlikely to produce excessive constriction by scar At first this was left attached by a pedicle to the pericardial sac This resulted in the risk of kinking the circumflex coronary and did not seem to be of any real advantage The bolster was then made as a free graft, taking precaution to fasten both ends of the sleeve to the cotton tape itself thus preventing "telescoping" of the sleeve on the suture

Pathology—None of the specimens in which the suture was prepared with pericardium showed either acute or chronic erosion (Table I)[17] The size of the ring remained essentially the same as that to which it had been tied except in 2 animals in which at autopsy the ring was thought to have been slightly reduced beyond the original size The observation period of one to six months in these 62 animals seemed adequate Note that in 9 of the 18 dogs in which the silk or cotton suture cut through it did so within a month (Table I)

TABLE I INCIDENCE OF EROSION

SPECIMEN EXAMINED IN		1 WEEK OR LESS	1 WEEK TO 1 MONTH	1 to 2 MONTHS	2 to 3 MONTHS	3 to 6 MONTHS	TOTAL
Silk	Eroded	5	2		1	6	14
	Did not erode	3	1				4
Cotton Tape	Eroded	1	1	1		1	4
	Did not erode				1	2	3
Cotton Tape and Pericardium	Eroded						0
	Did not erode	5	1	1	8	5	20
Criteria for judging erosion were met in							45
Criteria for judging erosion were not met in							17*
				Total			62

*Operative death after suture was placed 7
Operative death before suture was placed 4
Suture transfixing left atrial lumen
  Cotton tape 3
  Cotton tape and pericardium 1
Suture not tied 1
Suture could not be placed 1
17

All varieties of suture were well tolerated by the surrounding tissues There was a characteristic acute inflammatory reaction around the material occurring early which gradually subsided The cellular infiltration was replaced in a few weeks by a fibrous envelope surrounding the suture The reaction was somewhat greater around the pericardium covered segment where scarring occasionally resulted in a fibrous cord of up to 1 cm thickness The inflammatory reaction was generally greater in the animals nonaseptically operated upon and was minimal in the aseptically controlled group In no instance was there histopathologic evidence of damage to the ventricular myocardium as a result of trauma in the placement of the suture when the procedure was performed correctly Fig 7 shows some examples of the histologic features noted In 4 animals of this series, the suture was placed erroneously within the substance of the myocardium In these, the material was enveloped by fibrous tissue and surrounded by healthy muscle

There was some concern as to the fate of the segment of suture exposed to the blood flow within the right atrium It was thought that this might be a source of thrombo embolism It was soon observed, however, that, since the suture lay in contact with the surface of the septum, it was covered by a layer of fibrin and endothelialized within two weeks There were no instances of thrombosis at this site

There were a number of technical errors in the performances of the procedure These can now be avoided if due care is taken during each maneuver The obvious dangers are related to injury of important coronary branches Fortunately, these vessels are visible and can be easily by-passed Transfixion of a segment of the ring by entering the lumen of the left atrium at some point on its circumference is a serious error because this will not only leave a cord of suture across the lumen, which can be the site of thrombosis and origin of emboli, but also leads to erosion of the tissues by the suture at the points of perforation The risk of such transfixion is particularly great when attempting to pass from the right atrium into the transverse sinus At this point, there is a tendency to pull the left atrial appendage with the left hand as the needle is guided with the right This causes "tenting" of the atrial wall The apex of this tenting is at a point on the ring just posterior and medial to the anterior commissure and beneath the anterior base of the interatrial septum (Fig 8)

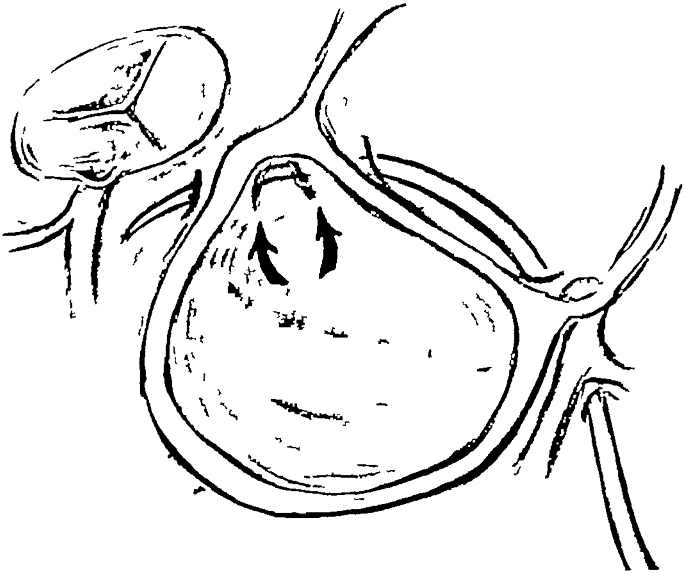

Fig 8—This diagram illustrates the tenting of the mitral ring as traction is made on the atrium to demonstrate the danger of transfixing the atrium at this point (See text.)

If one should lose control of the needle at this point there is strong possibility of transfixing this tented segment, crossing the atrial lumen just above the anteromedial commissure Another danger is the possibility of catching the right wall of the right atrium or the wall of the vena cava if the needle is advanced too far into the right atrium This was done in 2 animals In one of these a definite inferior vena caval obstruction resulted in the other the error was inconsequential In 2 animals the anterior wall of the right atrium, at the point of emergence of the suture was lacerated seriously These two errors are easily avoided if the point of the needle is kept close to the septum at all times

Electrocardiographic and Hemodynamic Studies—In order to evaluate the suggested operative procedure from the standpoint of possible damage to the heart muscle the conduction system the coronary circulation and, also in regard to potential hemodynamic alterations resulting from decreasing the size of an annulus which was not originally dilated electrocardiographic and pressure pulse tracings were used[18] These studies were done in 62 dogs in which a circumferential suture was placed The technical modifications which were made from time to time were of such a nature that they could not be expected to affect the outcome in regard to the points just enumerated Electrocardiograms were made in all the animals immediately preoperatively postoperatively at one two and six weeks and again at the time of reoperation one to six months after the initial procedure These tracings included the standard and unipolar leads as well as the usual six chest leads In 15 animals electrocardiographic tracings were also made after each of the important steps during the purse string suture procedure In 3 dogs coronary damage was suspected when they died without apparent cause The electrocardiogram in these however did not confirm this suspicion The lack of electrocardiographic evidence might have been due to the fact that the dogs died before serial tracings could be obtained In 2 other animals a coronary branch was obviously injured at surgery The injury could have been easily avoided if more caution had been observed In none of the others was there any definite electrocardiographic evidence of myocardial infarction or of conduction disturbances There were no arrhythmias except in two animals which showed a transient atrial fibrillation In 6 the changes noted were compatible with minor degrees of pericarditis attributable to the surgical procedure as a whole rather than to the placement of the circumferential suture itself

In 15 animals electrocardiographic tracings were taken during the operation and these were recorded after the following steps opening of the pericardium placement of the hemostatic purse string suture at the base of the left atrial appendage and tunneling of the circumflex coronary artery placement but before tying of the circumferential suture and twenty minutes after the suture was tied to 1.8 to 2.0 cm These tracings indicate that the majority of the changes could be attributed to the thoracotomy and pericardiotomy and were not specifically associated with the placement of the circumferential suture itself

An analysis of the left ventricular pressure pulse was undertaken as a means for the detection of possible myocardial damage which would not be re

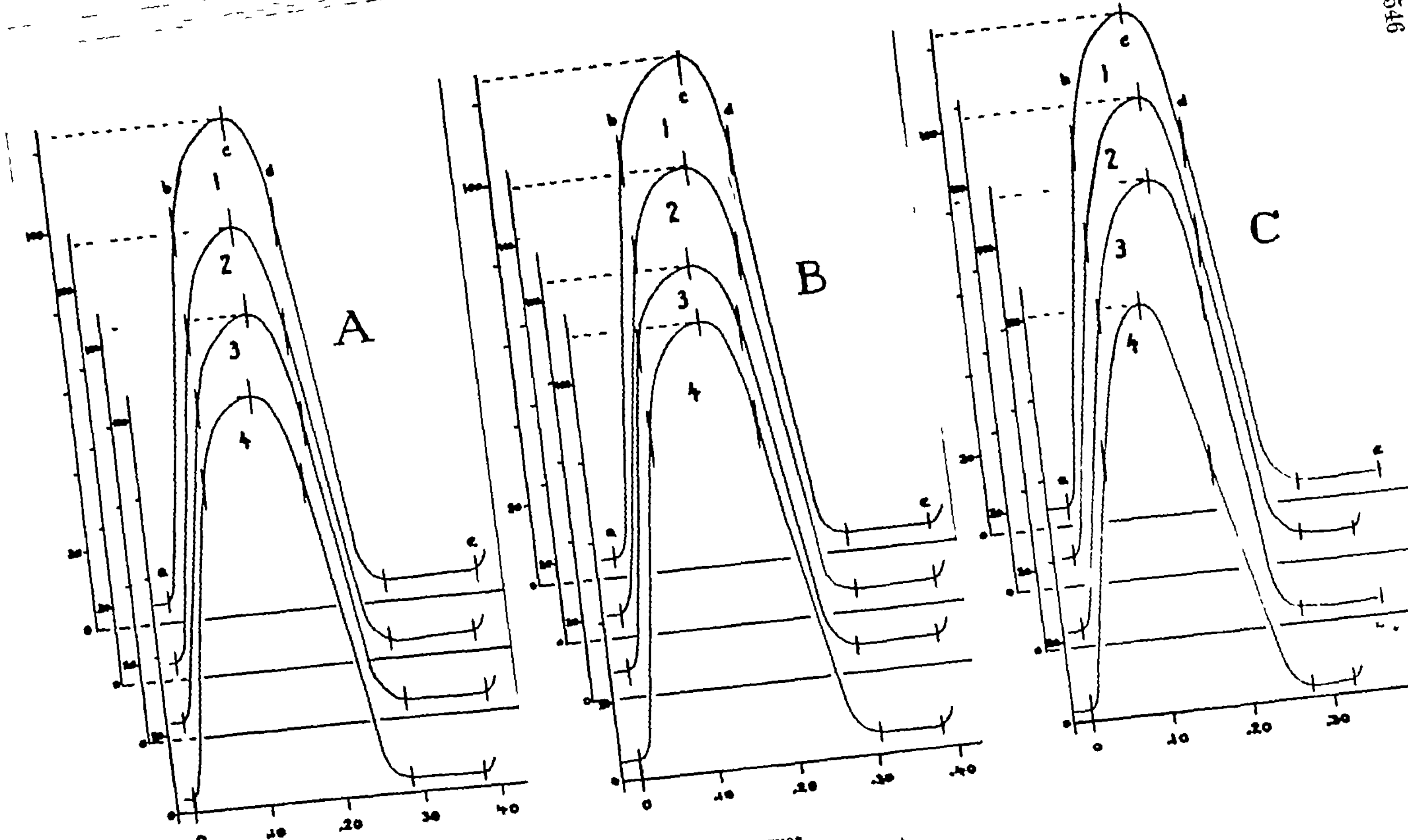

Fig. 9.—Average ventricular pressure curves.
1. Recordings taken initially after exposure of the heart.
2. After placement of the circumferential suture (not tied).
3. Five minutes after the suture was tied.
4. Twenty minutes after the suture was tied. (Plotted in mm. Hg as marked on the left against seconds as marked at the base.)
A. Average curves in 30 dogs.
B. Average curves in the survivors of those.
C. Average curves in 6 dogs suspected of having had coronary or myocardial damage.
(See text.)

vealed by the electrocardiogram. Average ventricular pressure curves were plotted to correspond to each of the following stages of the procedure: initial measurements, measurements with the circumferential suture placed but not tied, five minutes and again twenty minutes after tying the suture. These data are grouped in three categories (Fig. 9). Group A includes 30 animals thus studied, Group B includes those that survived the operation, Group C includes 6 dogs which died shortly after the procedure, in three of which coronary damage was suspected. A clear-cut cause of death was not found at autopsy in any of these 6 animals. Note that in the first two groups the only significant change in the ventricular curves was a drop in pressure. This can probably be accounted for on the basis of variable degrees of operative blood loss. In Group C, however, the final curve is not only lower but shows a significant alteration in contour. This change is compatible with reduced blood volume but myocardial damage as a result of trauma cannot be excluded.

Both the electrocardiographic and the pressure pulse tracings, then, appear to indicate that although there is most certainly a risk of damaging the coronary circulation and or the myocardium itself, when the operation is properly and carefully performed there is no evidence of significant damage to either. The total absence of conduction defects was also noted. The 2 animals in which transient auricular fibrillation was seen reverted to normal sinus rhythm by the end of the operation. A myocardial infarct was found at autopsy in only 3 animals of the entire group. In one a large lateral branch of the circumflex coronary was transfixed with the needle. This accident was obvious at the time of the operation and could have been easily avoided. In the other 2, although the operative technique cannot be held blameless, the infarction could well have been the result of an embolus since there were also multiple infarcts in the kidneys, spleen, and liver. These animals had a circumferential suture of silk which cut through into the left atrial lumen and accounted for the source of emboli.

Pressure measurements were taken in all animals. The studies in 12 dogs which died at operation were incomplete and are excluded from this evaluation. Figs. 10 and 11 show the graphs of the average pressure changes in the left atrium, pulmonary artery, left ventricle, and aorta. There was generally a slight or insignificant elevation in the left atrial pressure. There was usually an insignificant drop in pulmonary artery pressure. There was also a drop of more significant proportions in the left ventricular and aortic pressures. These changes were observed consistently to hold both in the acute and in the long term studies. It is difficult to attribute the minimal rise in atrial pressure to excessive narrowing of the A-V ring which, even though initially normal, was never reduced to a diameter less than 1.8 cm. (2.5 sq. cm.). The aortic and ventricular pressure drop is probably accounted for by operative blood loss of approximately 150 to 300 c.c. in animals averaging 35 lbs. in weight. In a group of 8 dogs which were supported with either saline, Methoxamine infusion, blood transfusion or both, the ventricular pressure was higher and the aortic better sustained than in those not supported in this manner (Fig. 11). The fall seen in the measurements taken at reoperation is due to blood loss again since here none of the animals were supported and blood loss was usually greater due to the need for reincision and reopening of a pleural symphysis usually associated with lung trauma The elevation in left atrial pressure seen in Group A of Fig 11 gave us some concern Since we had noted that in 7 dogs, in which the silk suture had cut through into the lumen, there had been a marked narrowing of the ring to a diameter of about 1 cm, the pressure determinations on these were averaged in order to compare them with the rest (Fig 12) We were quite surprised to find that there was hardly any elevation in atrial pressure and indeed a slight drop in pulmonary artery pressure The explanation of the left atrial pressure change, then, cannot really be on the

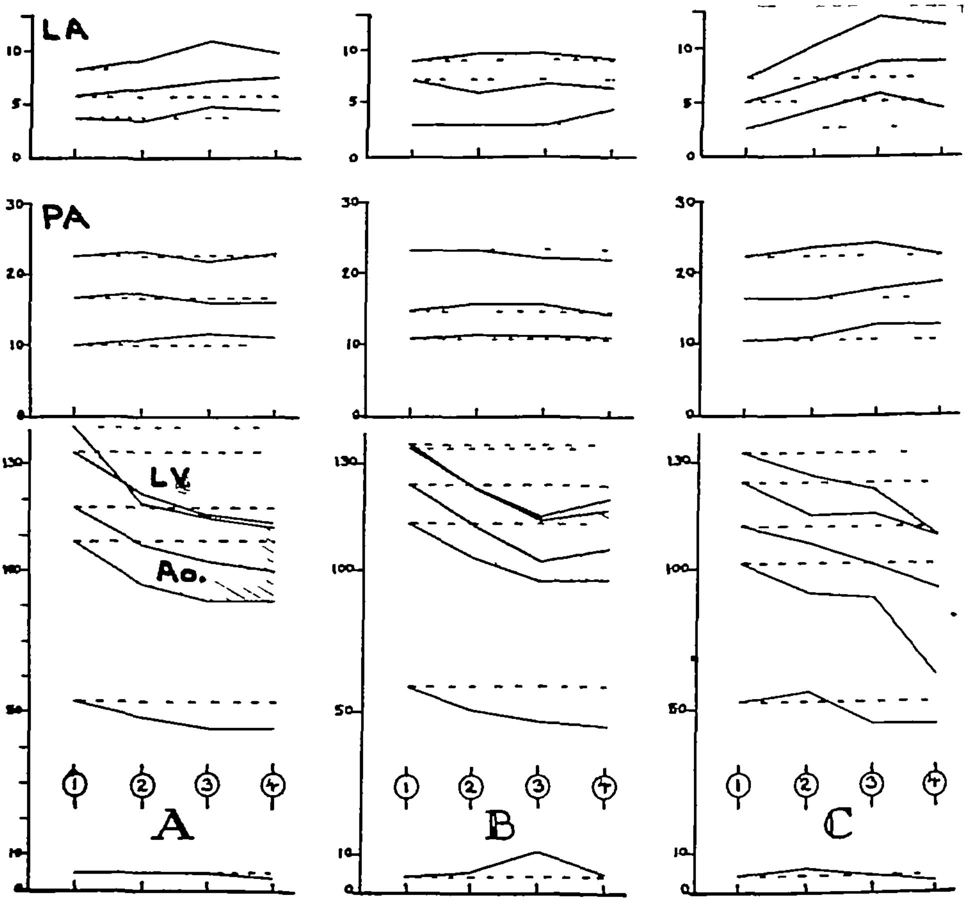

Fig 10—*Average pressures in*
A Thirty dogs operated upon by this circumferential suture technique
B Survivors of this group
C, Six dogs suspected of having had coronary or myocardial damage (See text)
1 Initial pressures
2 Circumferential suture placed but not tied.
3 Circumferential suture tied for 5 minutes
4 Twenty minutes after suture was tied

The upper graphs show atrial pressures The next pulmonary artery and the lowest aortic and left ventricular pressures Maximum mean and minimum pressures are charted in each step (mm Hg) basis of narrowing of the ring. Perhaps the slight rise in left ventricular diastolic pressure is a clue to circulatory disturbances attributable to minimal degrees of myocardial anoxia resulting from anesthesia or decreased blood volume or possibly to very minor degrees of transient left ventricular damage which when severe as in Group C (Fig. 10) might be responsible for the more obvious left atrial pressure rise. As far as the possibility that lowered ventricular and aortic pressures might be masking an otherwise significant elevation in left

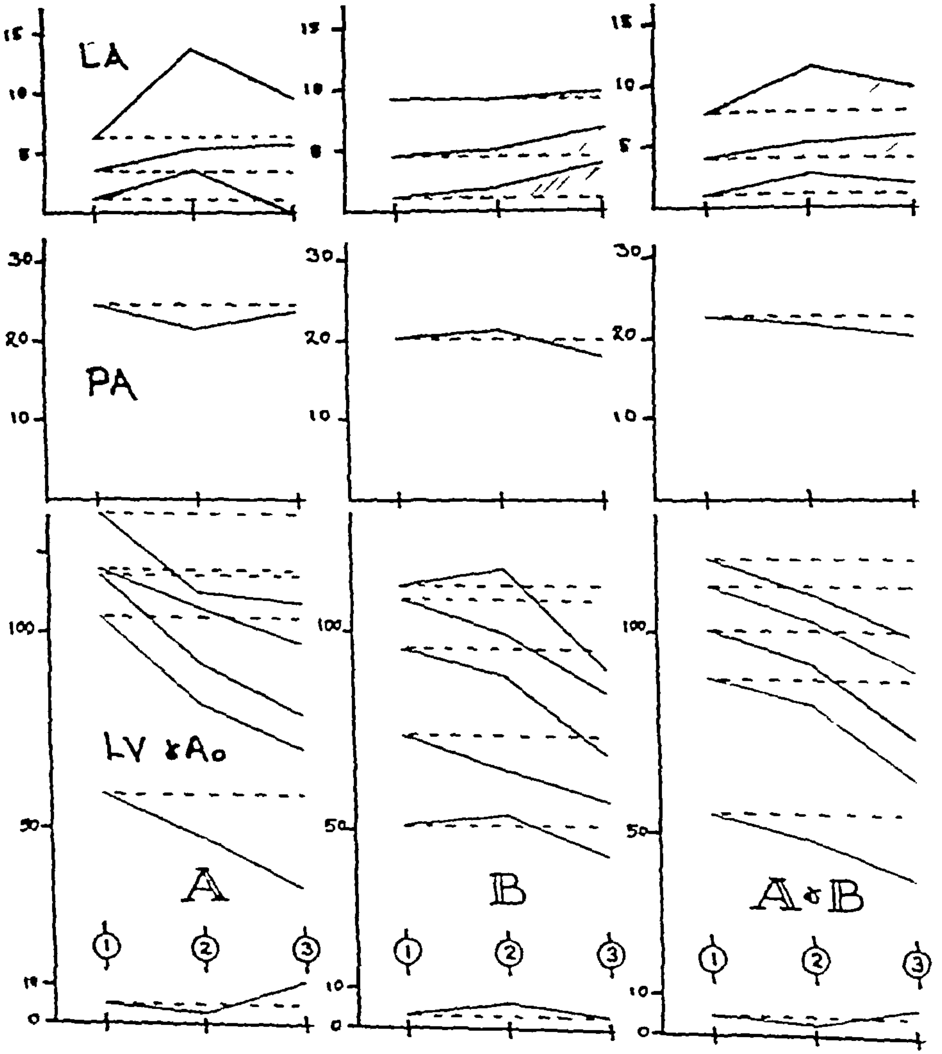

Fig 11 [illegible] ventricular and aortic pressures [illegible]
[illegible] during surgery
[illegible] with [illegible] and [illegible]
[illegible] initial [illegible]

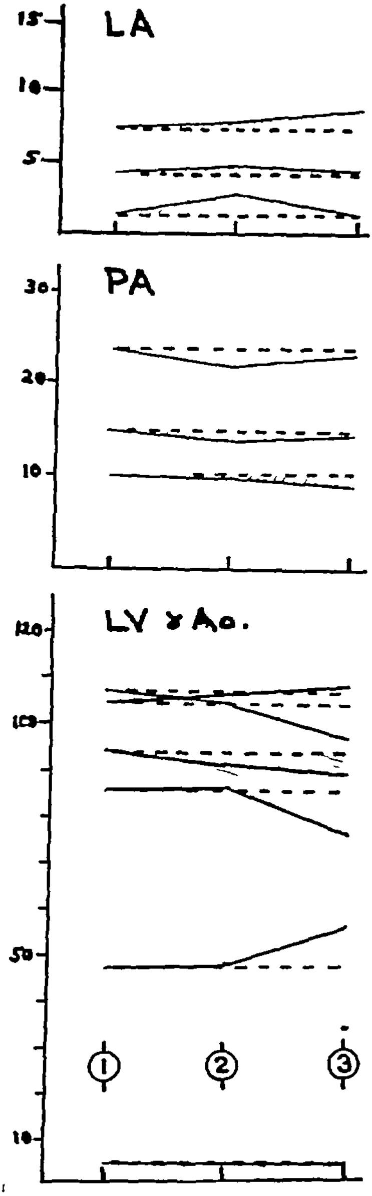

Fig. 12.—Left atrial, pulmonary artery, aortic, and left ventricular maximum, mean, and minimum in 7 dogs in which erosion of the suture had caused scar contracture of the ring to approximately 1 cm. in diameter.

1. Initial pressures.
2. Twenty minutes after tying the suture to 1.8 to 2.0 cm. in diameter.
3. One to six months postoperatively. (See text.)

atrial and pulmonary pressures is concerned it is interesting to note that in the dogs which were supported by transfusion or vasopressors and fluid there was no greater magnitude or concomitant elevation in the atrial and pulmonic pressures than that seen in the rest As a matter of fact the elevation was less significant than in those which were not so supported

The foregoing experimental work (presented in complete detail elsewhere[17, 18]) indicates that the suggested procedure was consistently effective in eliminating artificially produced mitral regurgitation that this operation can be performed with reasonable safety eliminating some of the early pitfalls and hazards that no significant damage was done to the heart when the technique was properly carried out The major danger of this procedure is that of erosion of the suture into the lumen of the atrium This complication was eliminated entirely by the simple modifications of the original technique described It is further shown that the degree of circumferential constriction herein employed even of the normal dog's atrioventricular ring produced only insignificant hemodynamic alterations

Past experience both in the surgery of mitral stenosis and in the study of pathologic specimens led us to believe that this principle was likely to be effective in a significantly large proportion of cases with mitral insufficiency

On this basis limited clinical trial of the operation was considered justified

INITIAL CLINICAL TRIALS

To the present time 7 patients in very severe states of marked to intractable chronic congestive failure associated with obvious mitral regurgitation have undergone surgery by this technique The salient features of these cases will be given here pending a detailed report after a more adequate follow up period has elapsed

CASE 1—R M a 28 year old white woman was operated upon on Jan 20 1955 with a diagnosis of predominant mitral stenosis mitral insufficiency and adynamic aortic stenosis Atrial fibrillation was present She had a history of rapidly progressing congestive failure unresponsive to medical care

At surgery the diagnosis of aortic stenosis was ruled out by direct examination and by pressure determinations in the aorta and left ventricle The left ventricular systolic pressure was 100 mm Hg and the aortic pressure just distal to the valve was 110 mm Hg The pressure in the left atrium was [illegible]/10 (17) mm Hg Digital exploration of the mitral valve revealed a marked mitral insufficiency with a Grade 3 regurgitant jet The orifice could admit 2½ to 3 fingers The leaflets were thickened but very pliable They were held taut by the shortened chordae tendineae and the greatly enlarged ring The commissures were [illegible] and slightly scarred and fused Although this was not the original plan placement of a circumferential suture was undertaken in view of the ideal type of valve defects and the rapid downhill clinical course

The technique followed was identical with that which has been described experimentally Although there was tremendous enlargement of the left atrium and moderate to marked enlargement of the left ventricle the procedure was carried out with surprising ease As the suture was tied [illegible] gradual and dramatic [illegible] of the [illegible] The ring was drawn down to a diameter of approximately 3 cm [illegible] The [illegible] to [illegible] fr[illegible] [illegible] [illegible] The [illegible] monitor [illegible] QRS [illegible] left atrium [illegible]

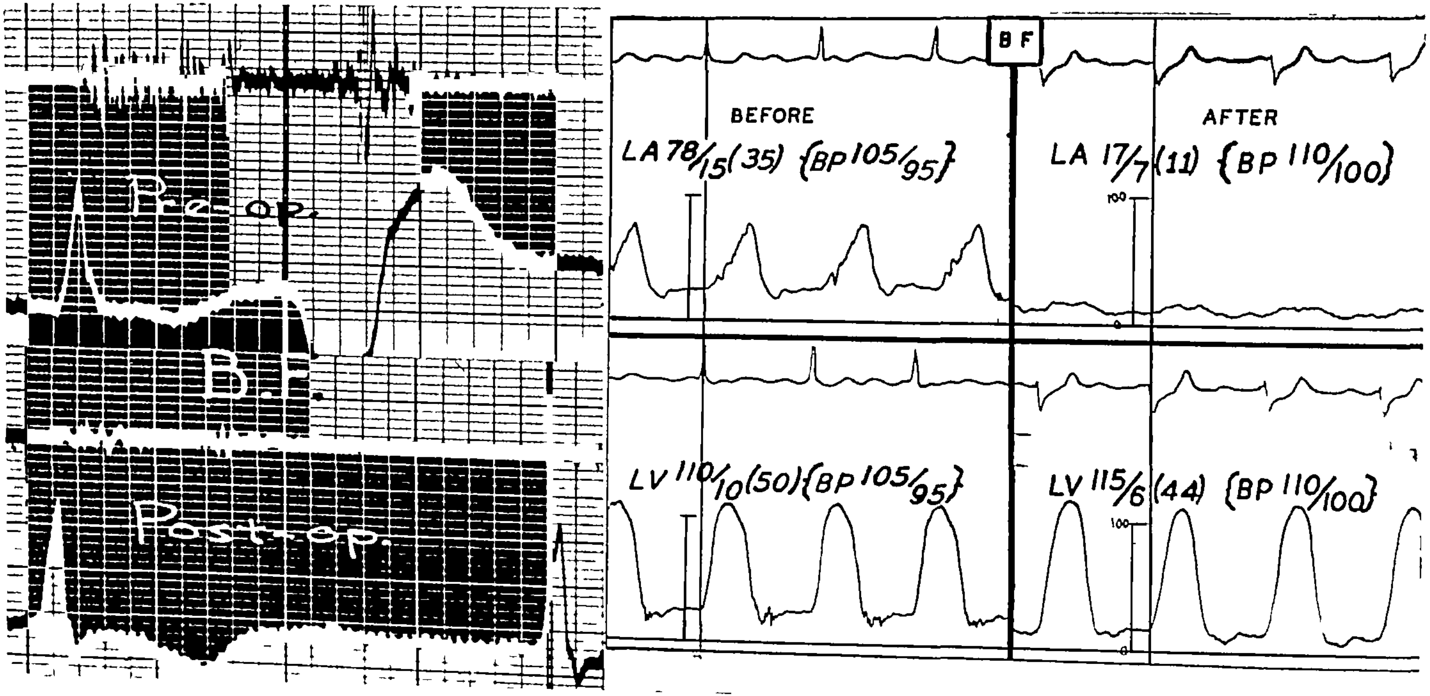

Fig 13.—Case 2. Left, pre and postoperative phonocardiogram. Right, pre and postoperative left atrial and left ventricular pressure pulses. Note the change in contour as well as in pressure. The S T segment depression seen in the electrocardiogram tracings during this recording was transient.

dilatation of the ventricle decreased visibly within a few beats after the suture had been tied. There was an obvious redundancy and flaccidity of the greatly enlarged atrial chamber. Further digital exploration revealed a barely palpable "whiff" of regurgitation in the posterior commissural region. Pressure tracings were repeated showing a drop in the left atrium to 19/7 (11) mm. Hg. The left ventricular pressure was now 112 mm Hg systolic. Blood loss and tolerance to the procedure were comparable to that of the usual mitral commissurotomy.

Postoperatively the patient had an uneventful recovery. Daily electrocardiograms showed no significant change. The x-rays of the chest revealed a significant decrease in the size of the heart within one week of surgery. The mitral systolic murmur had changed from a preoperative Grade 3 to a Grade 1. She was discharged on Feb. 9, 1955 (twentieth postoperative day). Her last visit was on April 18, 1955, at which time she stated that she had been doing all her housework except laundry for the past three weeks. She had felt very well, had no shortness of breath, and had been sleeping flat in bed. She continues to take digitoxin. X-rays showed persistence of the decrease in the cardiac size. The electrocardiogram remained unchanged except for marked digitalis effect. The phonocardiogram revealed a persistent mitral systolic murmur but greatly reduced in amplitude and duration. No mitral diastolic murmur was demonstrable.

CASE 2.—B. F., a [illegible]4-year-old white woman who had a previous mitral valve exploration in 195[illegible], was operated upon on Feb. 1, 1955. The preoperative diagnosis was predominant mitral insufficiency with auricular fibrillation and intractable congestive heart failure.

At surgery the heart was found to be of tremendous size, the largest which any of us had seen. The atrium was easily the size of a soccer ball. The pressures in the left atrium were 78/15 (35) mm. Hg, in the left ventricle 110/10 (50) mm. Hg, in the pulmonary artery 110/65 (84) mm. Hg. Exploration of the mitral valve through a rubber [illegible] appendage sewn into the anterior atrial wall revealed a ring which was enlarged to 4 or 5 fingers. The valve leaflets were shortened, tensed, and slightly thickened but quite pliable. There was no stenosis. The Grade 4 regurgitant jet was felt in all areas of the mitral orifice. The tricuspid orifice was easily [illegible] to 4 fingers. The circumferential suture was placed using the [illegible] technique. Here, however, the situation was complicated by the previous cardiac exploration which had resulted in pericardial scarring to the extent that it was *difficult* to identify with certainty the lateral coronary artery branches. Nevertheless, it was possible to place the purse-string suture without evident injury to these vessels. Difficulty was also experienced in the maneuver of threading the Reverdin needle as it emerged into the transverse sinus. The size of the heart made it necessary to exert considerable upward traction on the needle to make the threading of it possible. The regurgitant jet diminished, becoming barely palpable and localized to the region of the posterior commissure. The size of the left ventricle decreased visibly and promptly. The tension in the atrium also diminished until [illegible]. Tracings now revealed an atrial pressure of 17/7 (11) mm. Hg, [illegible] mm. Hg in the left ventricle, 10[illegible]/50 (75) mm. Hg in the pulmonary artery. A transient depression of the S-T segment in Lead II was the only electrocardiographic change during the operation.

In the early postoperative period the patient was hypotensive, requiring vasopressor drugs [illegible] pressure oxygen for two to three days. In twenty [illegible] the vital signs were stabilized. Thereafter the major difficulty consisted of [illegible] requiring [illegible] aspirations. After the third [illegible] useful [illegible] three or four episodes of [illegible] [illegible] The preoperative [illegible] disappeared [illegible] from [illegible] to 2 finger [illegible] Daily [illegible] abnormalities [illegible] ventricular [illegible] [illegible] April [illegible] 1955 [illegible] However [illegible]

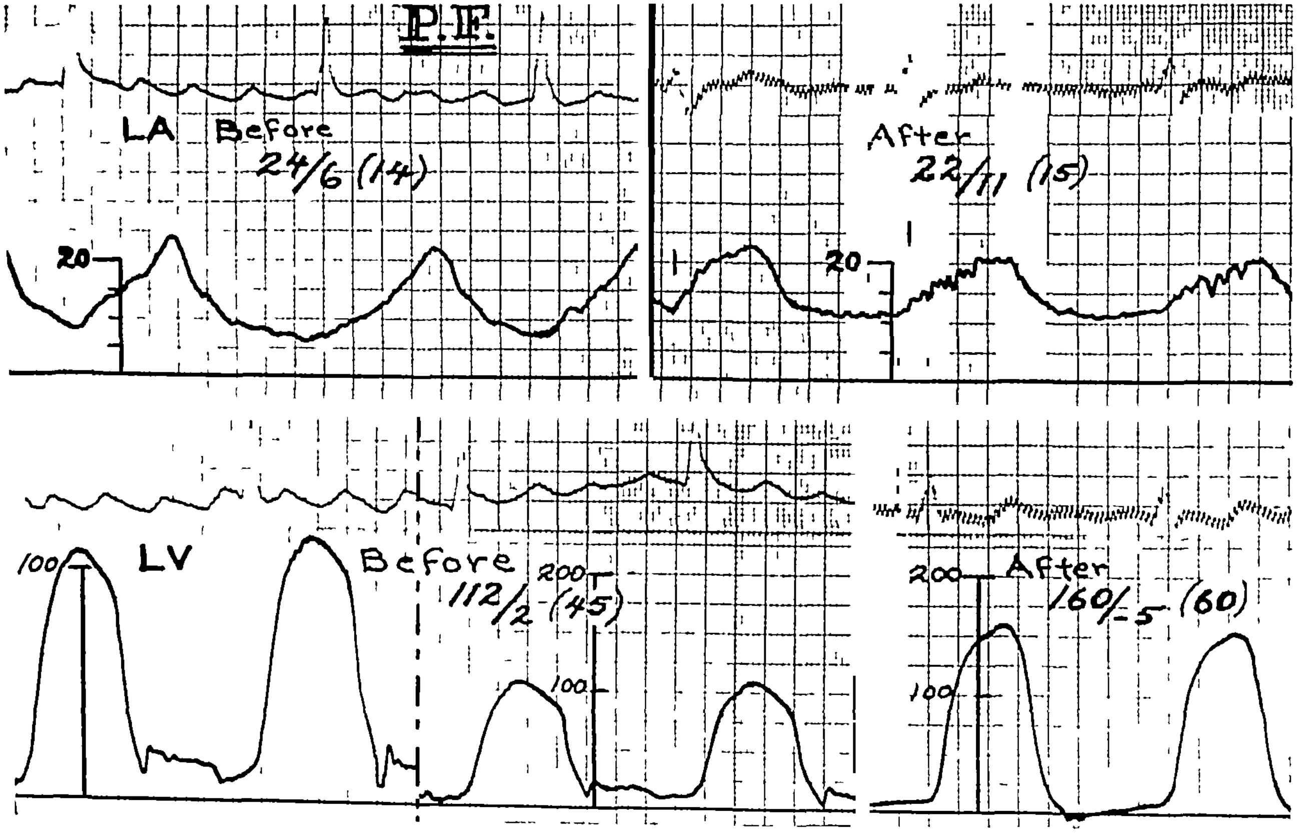

Fig 11—Case 3 The pre and postoperative pressure pulse tracings of the left atrium and ventricle are shown The negligible change in the atrial pressure is due to the fact that this patient had a severely calcified valve with stenosis and regurgitation which was seriously aggravated by commissurotomy The postoperative pressures and contours indicate that the regurgitation was diminished significantly The inability of the leaflets to regain a satisfactory degree of motility despite an adequate commissurotomy actually indicates possible persistence of a stenotic effect despite the fact that the effective orifice could admit 2 fingers

one week, ankle edema and progressive right heart failure returned, necessitating frequent mercurial diuretics. Her cough returned and she had minimal hemoptysis and slight fever. Antibiotics improved these symptoms in a "few days." The heart sounds had not changed. During the last week, she gradually became anuric and an increasing degree of ankle edema and hepatomegaly were noted. She died on April 1, 1955. An autopsy was not performed.

CASE 3.—P. F., a 27-year-old white woman, was operated upon on Feb. 24, 1955. The diagnosis was predominant mitral insufficiency with adynamic mitral stenosis, aortic stenosis, atrial fibrillation, and severe congestive failure.

At surgery the heart was found to be very large. There was a Grade 1 systolic thrill at the aortic valve. There was little deformity of the aortic valve as palpated externally. The pressure gradient across it was 30 mm. Hg. The left atrial pressure was 24/6 (14) mm Hg and that of the left ventricle was 112/2 (45) mm. Hg. The mitral valve was stenosed and insufficient. The effective orifice admitted 1 to 1½ fingers. There was considerable calcification in the region of the posterior commissure. The leaflets were moderately pliable although thickened and rolled. The annulus was only moderately enlarged. There was a Grade 3 regurgitant jet. A commissurotomy was planned after placement of the mitral purse-string suture. As the Reverdin needle was being manipulated around the annulus, the heart went into ventricular fibrillation. The needle was withdrawn at once. After twenty-two minutes of cardiac massage, multiple shocks and administration of drugs, the heartbeat was restored. At a second attempt, the circumferential suture was easily placed and subsequently the anterolateral commissure was opened. The regurgitation was considerably increased by the commissurotomy. The purse-string suture was then tied constricting the annulus to a size compatible with that of 2½ to 3 fingers. The effective orifice of the valve now would admit at least 2 fingers. The very severe degree of regurgitation decreased to the point where only a small jet could be felt in the region of the posterior commissure. Although the major part of the leaflets moved better after the operation, motion in the region of the posterior commissure was not greatly improved. The left atrial pressure was now 22/11 (15) mm Hg and in the left ventricle 160/-5 (60) mm. Hg. Although this represents a negligible change in the left atrial pressure, the change in ventricular pressure and the difference *in the atrial and* ventricular pressure pulse contours are indicative of considerable reduction of the regurgitation (Fig. 14). Postoperatively the patient did quite well despite a short interval during which hypotension required supportive measures. A left pleural effusion necessitated thoracentesis. The systolic murmur decreased considerably in intensity and the diastolic murmur likewise decreased in intensity. The postoperative x-rays showed slight decrease in size of the cardiac silhouette. The electrocardiogram did not reveal any abnormalities which were not noted preoperatively. The patient was discharged on March 30, 1955 (thirty-fourth postoperative day) and was last seen on April 14, 1955, at which time she stated that she felt better than she had [illegible] in years. She has been inactive as instructed and continues to take digitoxin. She has been completely free of the dyspnea, orthopnea, and ankle edema which she had preoperatively under this same regime.

CASE 4.—R. W., a 41-year-old woman, was operated upon on March 1, 1955, with the diagnosis of predominant mitral regurgitation with stenosis, adynamic aortic stenosis and insufficiency, chronic intractable congestive failure.

At surgery an enormous heart was found with a huge tensed left atrium and a large [illegible] left ventricle. There was induration about the aortic valve and a moderate degree of [illegible] dilatation. Pressure in the aorta was 130/55 (90) mm Hg, in the left ventricle [illegible] mm Hg, in the left atrium 28/11 (17) mm Hg, and in the pulmonary artery 54/25 (37) mm Hg. The mitral valve was badly calcified with an effective [illegible] which barely admitted 1½ fingers. The cusps were fixed, tensed, and rigid. The [illegible] was only moderately enlarged. There was a Grade 2 regurgitant jet. The anterolateral [illegible] was opened widely out to the myocardium. Since this improved the stenosis only partly because of the fixation of the leaflets, the posterior commissure had to be [illegible]. This required cutting through the calcium. The leaflets could not open to [illegible] which could have admitted 2½ fingers. However, there was now a [illegible]. A circumferential [illegible] was placed and tied until th[illegible] decreased in intensity to a Grade 1 or less. The effective orifice would still accommodate 2½ fingers. Aortic valve dilatation was considered but discarded in view of the stage of disease of the myocardium and in the face of a gradient which could probably not have been improved much. Pressures after the procedures were taken. In the left atrium it was now 17/6 (11) mm. Hg, in the left ventricle 150/−2 (55) mm. Hg, in the aorta it was 100/62 (80) mm. Hg, and in the pulmonary artery 54/26 (37) mm. Hg (Fig. 15). The immediate postoperative course was stormy. The urinary output was markedly depressed during the first three days. She was hypotensive and slightly cyanotic for about twenty-four hours.

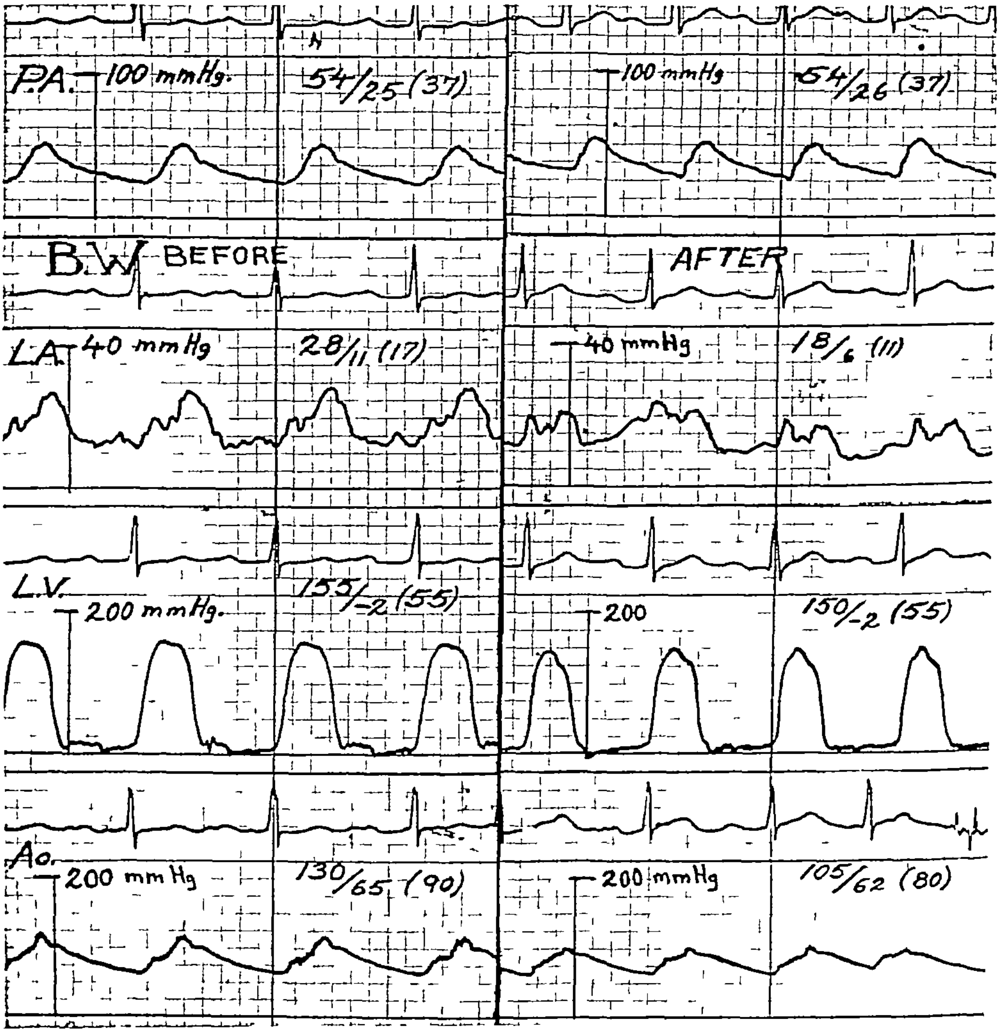

Fig. 15.—Case 4. Pressure pulse tracings pre- and postoperatively of pulmonary artery, left atrium, left ventricle, and aorta. Note the stenotic contour of the aortic curve.

This situation gradually improved and by the end of the first week the urinary output was adequate and the blood pressure stable. The daily electrocardiogram revealed no significant changes compared to the preoperative tracings. During the third week, she gradually became cyanotic, dyspneic, and edematous. A moderate electrolyte imbalance was noted. The liver became enlarged after having receded rapidly after surgery. The patient died on March 22, 1955 (three weeks postoperatively).

At autopsy, the heart was found to be enormous. The surgical wounds of the heart were healing quite well. There was extensive mitral valve disease as noted at operation. The degree of aortic stenosis was compatible with the evaluation made at surgery. In addition there was a tremendous degree of organic tricuspid insufficiency. The lungs were congested and fibrotic and showed several small areas of consolidation which could have been small infarcts. The liver was extremely large and showed marked cirrhotic changes. The commissurotomy was adequate. The valve cusps were rigid and required pressure to depress them. The circumferential suture was well placed, had elicited minimal gross tissue reaction and had not eroded through the encircled tissues. There was no evidence of myocardial infarction. The segment of suture lying in the right atrium adjacent to the septal surface was completely covered over by a translucent layer of glistening endotheliumlike tissue. There were no foci of thrombosis in the heart except for a small adherent thrombus in the dimple of the left atrial appendage stump.

Case 5.—L. T., was a 19 year old woman who was operated upon on March 3, 1955 with the diagnosis of mitral insufficiency, auricular fibrillation, massive cardiomegaly and intractable congestive failure.

At surgery, the left atrium was found to be the largest of all seven cases. The left ventricle was enormous and pale. The pressure in the left atrium was 38/5 (19) mm Hg, in the left ventricle 102/-5 (38) mm Hg, in the aorta 100/80 (87) mm Hg, and in the pulmonary artery 110/70 (82) mm Hg. There was no detectable aortic valve disease. The mitral valve was found to be pliable although somewhat thickened. There was Grade 4 regurgitant jet. The annulus could have easily admitted 5 fingers and the effective orifice at least 3 fingers. As preparations were made for placement of the mitral purse string suture ventricular fibrillation ensued. Placement of the suture had not been started. Massage was noted to be very inefficient because of the massive mitral regurgitation. However after repeated shocks, drugs, and massage, a weak beat was restored. It was decided that correction of the regurgitation was imperative and therefore placement of the suture was undertaken. At the moment that this was begun ventricular fibrillation returned. The circumferential suture was then placed while cardiac massage was carried out. Constriction of the ring could be felt to practically eliminate the regurgitation. At this point the thinned out left atrial wall tore resulting in considerable and rapid blood loss. After attempts to control bleeding and continued massage and resuscitation measures failed, the patient was pronounced dead.

An autopsy revealed an ideal valve for this method of correcting regurgitation. There was extensive pulmonary and hepatic damage and the myocardium was obviously of very poor quality. This specimen was studied on the pulse duplicator[19] with which cinematographic studies were made demonstrating clearly the correction of the regurgitation by the circumferential suture.

Case 6.—R. S., a 28 year old woman, was operated upon on April 19, 1955 with the diagnosis of mitral insufficiency, atrial fibrillation and chronic intractable congestive failure.

At surgery a very large heart was found. The pressures taken in the left atrium were 20-3 mm Hg, in the left ventricle 90/-8 mm Hg and in the pulmonary artery 22/12 mm Hg. Exploration of the mitral valve revealed a greatly dilated ring which could have admitted 4 to 5 fingers. The leaflets were thickened but moderately pliable. There was a plaque of calcium in the midportion of the anterolateral leaflet. The effective orifice could admit 3½ fingers. The circumferential suture was placed easily using a new needle specially designed for this procedure. This instrument facilitates threading and eliminates the need for cardiac dislocation during this maneuver. Tying of the suture reduced the ring to a size which could admit [illegible] finger and the effective orifice would still admit 3 fingers. The leaflets which were tense and immobile now moved freely. The Grade 4 regurgitant jet became a negligible faint posterior "whiff". The left atrial pressure was now 5-4 mm Hg, in the left ventricle 92/-10 mm Hg and in the pulmonary artery 24 [illegible] mm Hg.

The patient has had an uneventful and smooth postoperative course. The electrocardio[illegible] [illegible] changes in the first three postoperative days. There is now a faint [illegible] the Grade 4 preoperative murmur.

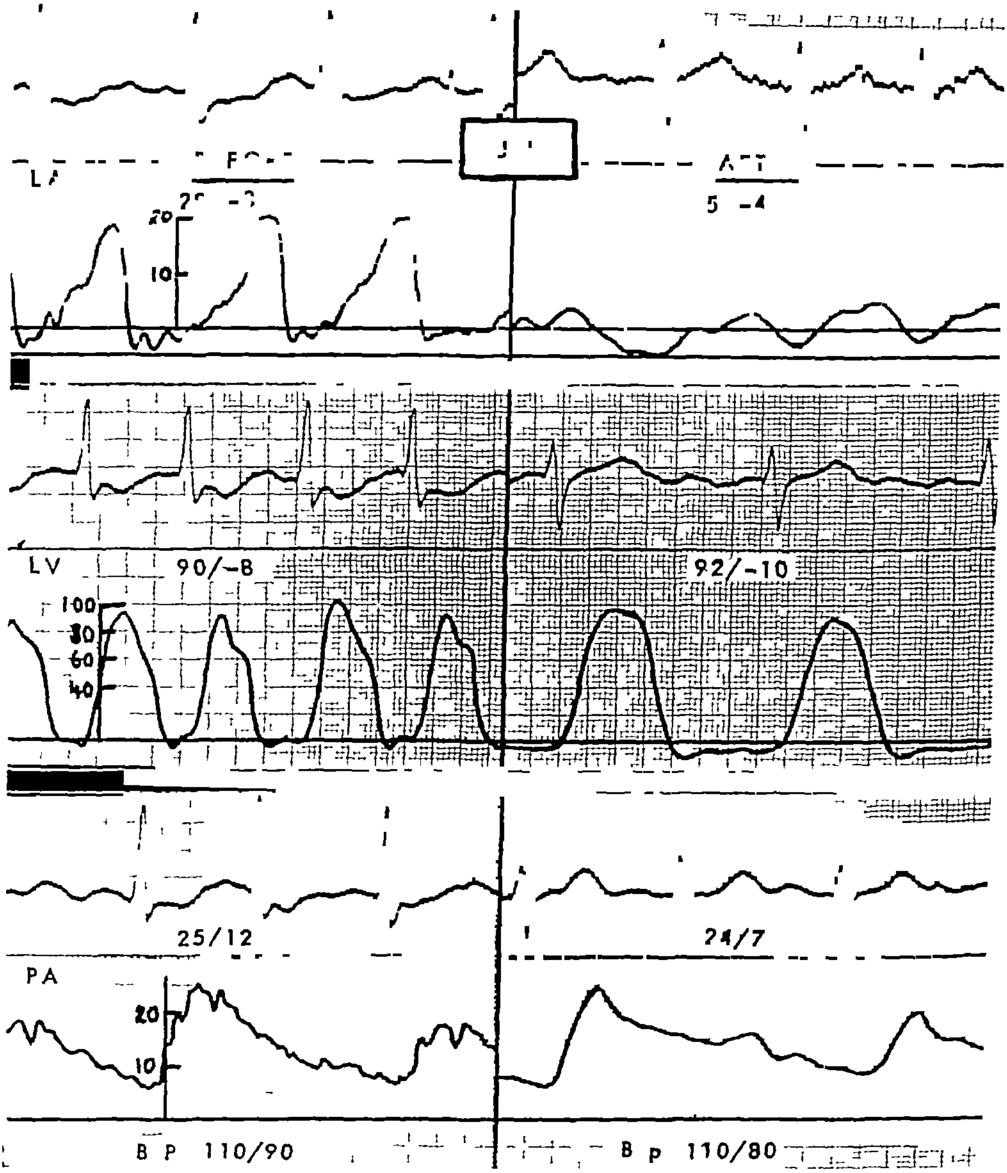

Fig 16 —Case 7 Note the remarkable changes in pressure and contour of both the atrial and ventricular pressure pulse tracings The change in the electrocardiogram was transient.

Case 7.—I. L., a 25 year old woman was operated upon on April 21, 1955, with the diagnosis of mitral insufficiency, atrial fibrillation, moderate left ventricular hypertrophy, and she had a previous history of subacute bacterial endocarditis. At surgery a very large heart was found. The pressure in the left atrium was 27/0 mm. Hg, and 80/-8 mm. Hg in the left ventricle. The mitral valve leaflets were thickened but quite pliable. The annulus was large enough to have admitted 5 fingers, the effective orifice 3 to 3½ fingers. The circumferential suture was placed easily with the new instrument and tied, reducing the annulus to a size compatible with 3 to 4 fingers. The tense, shortened leaflets were felt to relax and to come together easily in systole. The Grade 4 regurgitant jet changed to a barely perceptible "whiff." The effective orifice still could have admitted 3 to 3½ fingers. Pressures were repeated and found to be 10/0.5 mm. Hg in the left atrium, and 96/-4 mm. Hg in the left ventricle.

Postoperatively the patient had retained secretions requiring tracheal aspirations. A hypotensive state was controlled with norepinephrine. Her condition at the time of this report is fair and showing gradual improvement.

SUMMARY AND CONCLUSIONS

The rationale of circumferential suture of the mitral valve for the correction of mitral insufficiency is reviewed and discussed.

The results of experimental studies in the production and correction of mitral insufficiency as well as in the study of the problems associated with the development of the technique are reviewed and summarized.

Preliminary reports of the first 7 patients in whom this procedure has been tried are given.

The experimental work demonstrates that the regurgitation produced artificially can be eliminated. The procedure for circumferential suture or purse-string suturing of the mitral annulus has been perfected and in its present form has proved to be relatively simple and safe. When properly performed, no significant damage to the cardiac conduction system, the coronary circulation or the muscle itself can be demonstrated. No significant hemodynamic alterations can be attributed to the procedure in the experimental animals. Mitral stenosis is not produced.

Limited clinical trial in 7 severely ill patients demonstrated objectively and clinically that regurgitation associated with rheumatic heart disease can be corrected.

The final results of this procedure would appear at this time to depend upon the pathologic state of the valve. The myocardial, pulmonary, hepatic and renal status of the severely ill patients who have been operated upon appears to be the major cause of death in the 3 patients we have lost. For the immediate future continued clinical trial seems clearly justified. Until further experience has been acquired, however, the procedure should be applied only in critically ill patients.

It must be pointed out that although the technique in its present form is simple and easy to perform, a preliminary study of the pertinent anatomy and practice on experimental animals will be essential for its proper performance.

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DISCUSSION

DR RALPH A. DETERLING, JR, New York, N Y I arise to mention a patient in whom my colleague, Dr F F McAllister, in August, 1954, employed an annular purse string suture of cotton braided tape for control of mitral insufficiency She has had definite clinical improvement, although the x ray of the heart has not shown significant change

DR CHARLES P BAILEY, Philadelphia, Pa As you can well imagine, having been responsible for the so called "sash operation" for aortic insufficiency due to annular dilatation, we are very much interested in the operation proposed by Dr Davila and his associates

(slide) This sash goes under both coronary arteries, through both atrial chambers, and between the pulmonary conus and the aorta.

(slide) The one significant difference in application is that in our procedure the sash is put directly about the aortic annular level On the other hand, the mitral annulus laterally is found pretty close *to the atrioventricular junction, and in cases of* annular dilatation becomes displaced upward away from the apex So the external portion of the constricting suture that Dr Davila is using, since it lies within ventricular wall tissue, is placed significantly below the anatomic level of the annulus

(slide) The medial portion of the suture is placed outside the trigone, but actually this is not the region in which the inner portion of the annulus should be Of course, it can be put there and I do not mean to criticize their technique, but wish to point out something that we have observed in our own experience with the aortic valve, that I think would undoubtedly be pertinent here (slide) Here is the brachial artery tracing in a patient with severe aortic insufficiency during surgery immediately before applying the sash. Here is the change in the brachial arterial pressure tracing brought about by tightening the sash. We obtained a nice diastolic elevation and practically a normal contour.

(slide) Two weeks later when we reoperated on him you see the reversion of the pressures in the brachial artery, a change to a condition of considerable restoration of insufficiency. Further tightening of the sash, as you see, changed the condition to one indicating some stenosis but relief of the regurgitation.

The reason for the observed early loss of constriction is that soft tissue lying between the sash and the annulus cuts through gradually from the pressure against the underlying aorta or ventricle. Since much larger amounts of muscle mass are included within the constricting suture in Dr. Davila's method of tightening the mitral annulus, it would seem to me that loss of restraint due to such pressure necrosis must necessarily be much more pronounced. Perhaps improvement in the technical details will overcome that difficulty which I think otherwise must cause loss of the effect of overcoming regurgitation.

DR. MARK M. RAVITCH, New York, N. Y.: We are very glad to hear that Dr. Glover and his associates have found a practical and satisfactory method of approximating the lips of the annulus. This problem is being studied in our laboratory by Dr. Robert Wilder and Dr. Howard Moscowitz, whose work it is that I am showing.

(slide) One of the risks involved in such a circular suture, of course, is that one is producing a controlled type of mitral stenosis. Here is a tracing of atrial, ventricular, and aortic pressures in a normal dog; here a tracing in a dog with mitral insufficiency with a sloping systolic rise in auricular pressure; and here a mitral stenosis of considerable degree with a sharp gradient across the valve and higher auricular than ventricular pressure in diastole.

(slide) When one starts to operate in an animal with mitral insufficiency and cinches down with a purse-string suture above the annulus, one produces, as one might expect, a characteristic stenosis of variable degree and the problem may be one of producing a controlled stenosis which will not ultimately become dynamically significant. The motion picture strip which we have will demonstrate another method of investigating the mechanics of mitral insufficiency. For orientation purposes the next slide shows you the appearance of a percutaneous injection of radiopaque material into the left ventricle, demonstrated by an ordinary spot film.

(slide) This shows a dog with mitral insufficiency; you see the auricle filled with dye, the left ventricle, the sinus of Valsalva.

(slide) This shows a competent mitral valve, and I would urge you to watch the motion picture for a thin black line which appears to be the annulus; it may represent the accumulation of a little contrast medium under the edge of the annulus.

(Motion Picture) This is an ordinary catheter angiocardiogram for orientation. Here is the right side of the heart and you see the pulmonary artery, coming down the left auricle and left ventricle filling, and the aorta. Notice by the way how long it takes for the heart to empty and how irregular the admixture appears. Here is the needle being placed into the left ventricle. There is the mitral ring and the little line; notice the blood swirling around the ventricle and swept away by the leaflet of the valve. Here is an intact mitral valve. Note the straight ventricular border at the line of valve closure. This is an insufficiency of relatively slight degree, and the next is another major insufficiency, much the same kind. It is a great [illegible] that you can actually see the reflux of the contrast medium; you can simply see the auricle fill rapidly. The next animal had a very minor degree of insufficiency and you can see here a little swirl of [illegible] tiny up in a little [illegible] around the [illegible] of the [illegible].

Dr. Wilder and Dr. M[illegible] are also [illegible] the problem with respect to auricular [illegible] [illegible] [illegible] it would appear from repeated study of such films [illegible] [illegible] [illegible] of mitral insufficiency.

This is a very simple examination and may serve to indicate a possible method of diagnosing mitral insufficiency and assessing the value of a corrective procedure The motion pictures are taken with the Phillips screen intensifier

DR HARRISON BLACK, Boston, Mass I would like to congratulate Drs Davila, Glover, and associates on the very excellent presentation of correction of mitral insufficiency as shown in the movies of the perfused heart On Dr Harken's services, in Boston, we have also been impressed with the potentialities of constricting the annulus of the mitral valve for correction of regurgitation In fact, a different method of achieving annulus distortion was included in our report on the correction of mitral insufficiency before this Association last year Implicit in this approach is an appreciation of the fundamental importance of avoiding interference with leaflet mobility that we have stressed many times in the past

I would like to add a three dimensional concept of the dynamic pathology of pure mitral insufficiency that has evolved from our studies of this condition In addition to loss of leaflet substance due to the rheumatic process and the ensuing dilatation of the annulus, there occurs a sliding hernia of leaflets over the fibrous annulus further shortening them and rendering them more incompetent This alteration develops because of the aneurysmal dilatation of the left atrium which sags downward toward the diaphragm This observation has been independently made by Edwards of the Mayo Clinic We have found that external bolstering of the aneurysm of the left auricle can correct, to a certain degree, this sliding hernia of the leaflets and reduce or correct mitral regurgitation at the operating table Some attention to this factor will probably play a role in our eventual methods for correction of mitral regurgitation

Another approach, which is currently under investigation in our laboratory, is to plicate the mitral annulus posteriorly under direct vision in the opened left auricle during hypothermia Whichever of these methods eventually proves the most useful, the principle of bringing the leaflets into approximation by reducing the size of the annulus appears to be promising

DR EARLE B KAY, Cleveland, Ohio I should like to congratulate Dr Davila and Dr Glover on their very excellent presentation We have also employed the concept of the dilated mitral annulus in the surgical correction of mitral regurgitation It is our interpretation that after the annulus once dilates as a result of left ventricular hypertrophy and dilatation, this becomes the most significant factor in the perpetuation of this entity

(slide) In pure mitral insufficiency, the regurgitant stream of blood can be detected by the intracardiac finger being directed through the separated posterior medial commissure toward the atrial septum and posteriorly This regurgitant flow can be entirely eliminated if pressure is exerted upward by a finger placed posteriorly at the atrioventricular ring Such pressure decreased the size of the dilated ring and separated posteromedial commissure We have found that this same sequence of events can be accomplished by inserting a suture, followed later by a tubed pericardial graft based anteriorly through first the anterior segment of the dilated annulus adjacent to the posteromedial commissure, then through the posterior segment of the annulus, and to exit posteriorly on the ventricular side of the coronary sinus This graft is brought through an opening in the posterior pericardium, to which it is sutured after the optimum degree of tautness is obtained by the assistant pulling on the graft with one hand and pushing upward on the posterior aspect of the heart with the other, as directed by the surgeon s intracardiac finger

We have operated upon 7 patients with the past year employing this technique There were no operative deaths Two patients died later, 1 several days after leaving the hospital, from what was thought to be a pulmonary embolus, and the other four months later from progressive multivalvular disease

DR DAVILA (Closing) —Several points were brought up which I thought might be answered now, or at least clarified The first concerns the level of the purse string suture when it is placed It is not below the ring, it lies actually, if anything, a little above the ring, because the suture seems to find its way into the groove adjacent to the ring as it is tied

It remains there and specimens as long as six months after the operation was performed in dogs have shown that the size of the constriction remains the same as when originally performed.

Dr Kay has presented a very interesting procedure which brings up a question concerning the danger of material placed across the lumen of a chamber. In some of our dogs originally when we were having trouble with the suture cutting through a cord of silk would lie across the lumen of the left atrium and we had a tremendous incidence of embolic accidents in these animals.

One other point in connection with partial constriction procedures of the ring is that they are only partial. The total encirclement of the ring has the additional advantage that potential further dilatation of the ring in a case in which total regurgitation has not been eliminated will be prevented from producing the progressive enlargement of the ring of which we are all aware. Mitral stenosis was of course a very prominent concern in this study. We have found a slight to moderate elevation in the left atrioventricular gradient in the acute state in the dogs in which we have done this procedure. It must be remembered that experimentally one is constricting a ring of normal size. The elevation which has been seen in the dogs has not been seen in the patients in whom this procedure has been performed. We do not think that mitral stenosis when the procedure is performed adequately will be a significant hazard.

The delay in emptying of the left heart in the angiocardiograms shown by Dr Ravitch is an interesting point. In our pulse duplicator we injected dye into the chambers of a heart with mitral regurgitation as it was pumping. One could obviously see a very prolonged delay in emptying of the left heart. This has promise as a possible valuable diagnostic measure.

STUDIES ON THE FUNCTION OF THE HUMAN VAGUS NERVE IN VARIOUS TYPES OF INTRATHORACIC DISEASE

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ALBERT E ROBERTO, M D (BY INVITATION), AND
FRANK P SALOMONF, M D (BY INVITATION)
EMORY UNIVERSITY, GA

A CONSIDERABLE interest in the problem of the function of the autonomic nervous system in relation to the various types of pulmonary pathology has been expressed in previous publications by our group[1-5] Our studies have impressed upon us the need for detailed investigative studies relative to the function of the human vagus nerve in various disease states which involve the intrathoracic organs

A sizable literature has accumulated relative to physiologic studies upon the right ventricular and pulmonary arterial pressure in chronic pulmonary emphysema and pulmonary fibrosis To our knowledge, these studies have been confined to cardiac catheterization techniques in patients with an intact chest wall Recently, a cumulative group of studies has been presented relative to both cardiac catheterization studies, direct intracardiac, and direct intracardiac and pulmonary vascular pressure measurements in various types of cardiac defects An excellent review of such findings can be read in the recent monograph of Altschule[6]

A brief review of the knowledge concerning right ventricular and pulmonary vascular pressures in pulmonary fibrosis and chronic pulmonary emphysema seems merited In pulmonary fibrosis, the right ventricular and pulmonary arterial pressures are normal or elevated[7-10] An excessive rise in pulmonary artery pressure during exercise is characteristic[11, 12] Anoxia occurred as a definite factor in the elevation of pulmonary arterial pressure in pulmonary fibrosis[9, 13, 14] A normal pulmonary capillary pressure is usually seen[9, 13]

The findings in pulmonary emphysema reveal that the right ventricular pressure may be normal or high,[6, 7, 15] and an excessive rise during effort may be noted[17] In a similar fashion, the pulmonary artery pressure may be elevated[15, 18, 20] Fowler,[21] in 1950, suggested a neurogenic mechanism for this phenomenon when he revealed that tetraethylammonium chloride lowers an elevated pressure without changing the pulmonary capillary pressure (which was normal to begin with) Pulmonary artery pressure rises with exercise whether initially normal or elevated[11, 18] Yu and his associates[23] have suggested that pulmonary hypertension may be related to both anoxia and hypercarbia Normal right auricular pressures and pulmonary capillary pressures have been reported[22] A postural effect has been noted in that the pulmonary

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From Division of Thoracic Surgery Department of Surgery Emory University Clinics and School of Medicine Emory University Ga

Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City N J April 24 to 26 1955 arterial pressure is lower in the erect than in the supine position in patients with emphysema but not in normal subjects.[24]

PURPOSE AND PLAN OF THE EXPERIMENT

The fundamental purpose of the experiment is an attempt to increase our basic knowledge concerning the physiologic and the pathophysiologic function of the human vagus nerve in relation to pulmonary vascular dynamics.

There have been two fundamental experimental plans involved. First, a group of patients having certain pathologic pulmonary states have been studied by cardiac catheterization while conscious and with the chest wall intact. The effect of parasympathetic paralyzing drugs upon the right ventricular and pulmonary arterial pressures in such patients has been studied. In a second group of patients (Fig. 1) studies have been carried out upon the effect of (a) direct unilateral vagus nerve block with 1 per cent Novocain and (b) pharmaceutical block (atropine sulfate) upon direct pulmonary arterial and pulmonary venous measurements at the time of thoracotomy in various pathologic pulmonary and cardiovascular conditions.

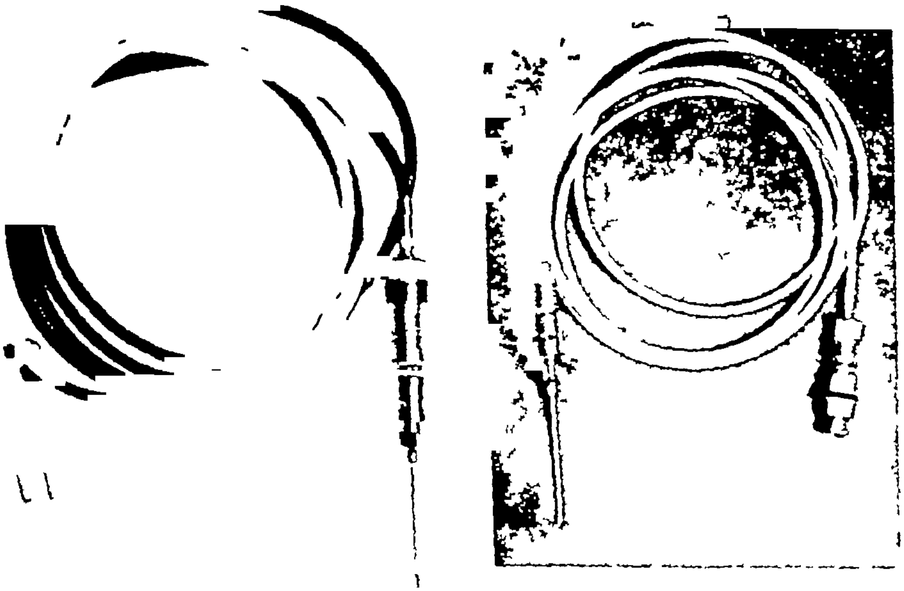


Fig. 1.—Type of equipment used for direct measurement of intraluminal pressures at thoracotomy. At the left is a Hathaway reluctance pressure transducer. At the right is a plastic catheter (filled with saline) attached to a Sanborn strain gauge manometer. All pressures were recorded on a Sanborn DuoViso Cardiette.

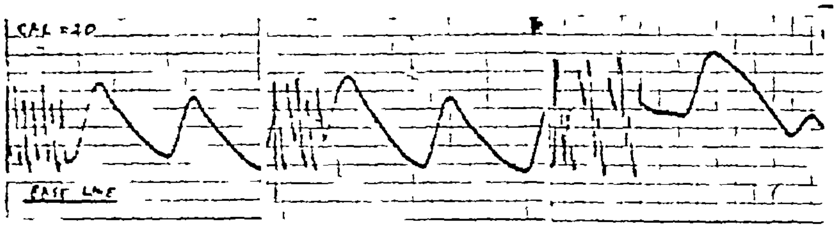
DETAILS OF EXPERIMENTAL METHOD

In the first group a standard cardiac catheterization technique was incorporated, not involving the preliminary administration of any drugs. Particular attention was paid to obtaining baseline measurements of the right ventricular and pulmonary arterial pressures both at rest and with a standard exercise test The time for return of an elevated pressure, after exercise, to the original base line was recorded in several instances Similar measurements were then repeated within the same cardiac catheterization after the intravenous administration of certain drugs known to have the capacity of producing a pharmacologic block of the vagus nerve In one group of patients, 30 mg of Pro-Banthine was given, and in another, 0 65 mg of atropine sulfate was administered Following the catheterization, a comparison of the pressure measurements at rest and during exercise was made in all patients In a small group of patients, the time required for an elevated pressure, with exercise, to return to normal before and after the vagal blocking agent was analyzed

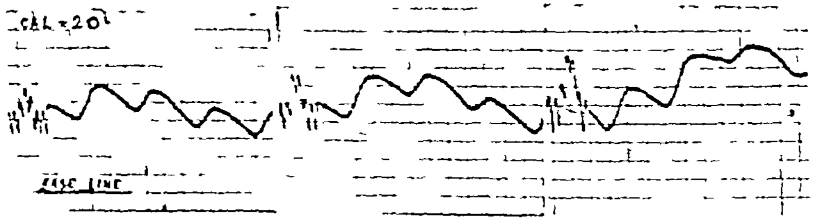
In certain instances, patients who had undergone preoperative cardiac catheterizations of this type were subsequently studied by direct pressure measurements of the pulmonary artery and/or pulmonary vein at the time of thoracotomy A comparison of such studies will be included in a later communication Furthermore, in some instances, concomitant pressure studies of the pulmonary vein and pulmonary artery were accomplished, but the number of such studies is still too limited to warrant description at this time

In the second group of patients, direct pressure measurements were carried out by the introduction of a No 18 or a No 20 gauge needle directly into the pulmonary artery just before its lobar or segmental branching In other patients, direct pressure measurements were carried out in either the superior or inferior pulmonary vein before its entry into the pericardial sac In all but one patient, the operative position was either the right or left lateral decubitus In one instance, measurements in the face down (Overholt) position were carried out

A sincere attempt to standardize the baseline conditions of the patients was incorporated throughout the study Similar preoperative sedation, involving morphine sulfate and barbiturate, was maintained and no studies were performed less than two hours after such preoperative medication The time of administration of a standard dose of atropine sulfate (which in this Clinic is given intravenously at the time of induction with Pentothal sodium) was recorded Pressure measurements were taken at least seventy-five minutes following the administration of the induction dosage of atropine The type of anesthesia was constant throughout and incorporated Pentothal sodium or Surital induction, production of apnea by succinyl choline chloride (Anectine), and maintenance of apnea by slow drip of this drug Nitrous oxide (65 per cent) and oxygen (35 per cent) were given to maintain analgesia and adequate oxygenation In all instances, endotracheal intubation with positive pressure was used A constant and controllable ventilatory pressure was maintained with the Rand-Wolf Respirator The direct intravascular pressure measurements were made satisfactorily after the vessel was first isolated for study In patients in whom a direct vagus nerve block was incorporated the vagus nerve was dissected out so that it could be injected under direct vision at a level at least 3 cm above the bifurcation of the trachea Intravascular pressure tracings within the pulmonary artery or vein were then obtained at ventilatory pressures ranging from 0 to 5, 0 to 10 and 0 to 20 mm Hg (Fig 2) The immediate effect of such a ventilatory pressure was recorded and recordings repeated 1, 2, and 3 minutes after the institution of such pressure. In some instances where dampened curves were being obtained during the first three minutes recordings as late as six minutes after assumption of a specific ventilatory pressure were made. It is significant to note that the pressure within the pulmonary vessels assumed the average significant pressure tracing within the first minute in all instances with few exceptions. These exceptions consisted of 5 patients in whom a vagovagal type of reflex with drop of systemic blood pressure and pulse was produced after two or three minutes at a ventilatory pressure of 20 mm Hg. In 3 of these patients the underlying disease was mitral stenosis and in 2 the underlying disease was pulmonary emphysema of hypertrophic type.



ML PAP BEFORE BLOCK
VENT P = 0 → 5 VENT P = 5 → 10 VENT P = 10 → 20



ML PAP AFTER BLOCK
VENT P = 0 → 5 VENT P = 5 → 10 VENT P = 10 → 20

Fig. [illegible].—Tracings of direct intraluminal pulmonary artery pressures taken at thoracotomy (fast and slow speed) [illegible] recorder. Tracings at varying ventilatory pressures demonstrating the [illegible] rise in pulmonary artery pressure as ventilatory pressure was increased. [illegible] of the vagus nerve with atropine sulfate produced tachycardia, elevation of diastolic [illegible] tachycardia, elevation of diastolic pressure but no change in systolic pulmonary artery pressure. (Patient M. C. had right middle lobe bronchiectasis; remainder of the pulmonary tree appeared normal.)

Following these determinations the pressure tracings were studied in regard to the effect of various ventilatory pressures in different diseases and the effect of either direct vagus block or pharmacologic block upon such pulmonary vascular pressure responses to varying levels of ventilatory pressure.

During the periods of this study experience with 6 patients showed us that strikingly abnormal ventilatory pressures may in themselves produce a vagovagal type of reflex even in the presence of a unilateral direct vagus nerve block or pharmacologic block with intravenous atropine. A reversal of this type of reflex could be obtained by resumption of normal ventilatory pressures alone. [illegible] by-product of the experiment was

TYPES OF DISEASE STUDIED

Cardiac catheterization studies involving the conscious patient with the intact chest were carried out upon 18 patients. The types of disease involved in this study are shown in Table I.

TABLE I. TYPES OF DISEASE STUDIED

DISEASE	NUMBER OF PATIENTS
Hemoptysis, unexplained (normal pulmonary function, MBC 160 L./minute)	1
Pure bullous emphysema	1
Mixed bullous and hypertrophic emphysema	2
Hypertrophic emphysema, Class III (bilateral)	10
Hypertrophic emphysema, Class IV (fixed)	4
Total	18

MBC—Maximum breathing capacity.

TABLE II. PULMONARY ARTERY PRESSURE DISEASES STUDIED WITH OPEN CHEST

DISEASE	NUMBER OF PATIENTS
Misc. cardiovascular disease	8
Granulomas	3
Primary pulmonary carcinoma	3
Bronchiectasis	4
Pulmonary emphysema	
Bullous	1
Mixed	1
Class III	9
Total	29

Direct pulmonary artery pressure measurements were carried out upon 29 patients. The types of disease involved in this study are shown in Table II. To date there have been 7 direct pressure measurement studies upon the pulmonary vein, and the types of disease so far involved in this method of investigation are designated in Table III.

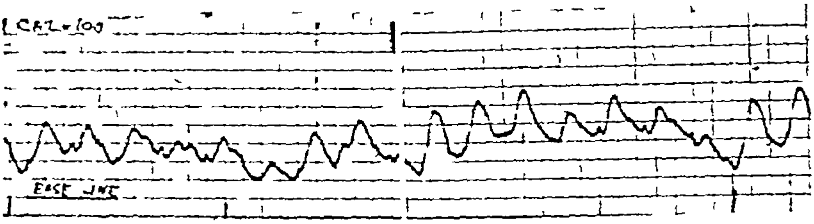
TABLE III. PULMONARY VEIN PRESSURES DISEASES STUDIED WITH OPEN CHEST

DISEASE	NUMBER OF PATIENTS
Bronchiectasis	2
Granuloma	1
Granuloma and emphysema	1
Emphysema	2
Mitral stenosis	1
Total	7

EXPERIMENTAL DATA AND RESULTS

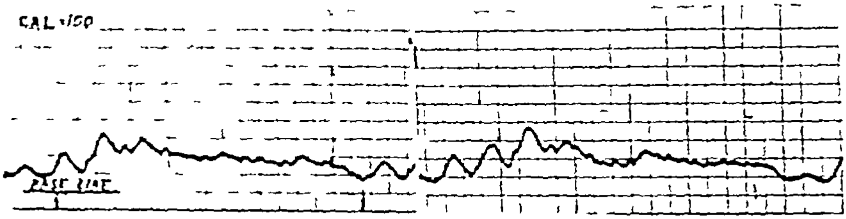
Inasmuch as a rather impressive number of figures are obtained with 4 to 6 different pressure studies in the individual patient, it was thought advisable to present a combination of tables. In each instance, therefore, the initial table shows the specific data with the actual recordings for each patient, and a sub-table is then presented, outlining the fundamental type of response demonstrated in each patient group at rest or with stress (exercise or high ventilatory pressure), prior to the use of a blocking agent and similar studies thereafter.

Cardiac Catheter Studies (Patient Conscious, Chest Wall Intact).—A total of 18 patients were investigated by means of cardiac catheterization. Right ventricular and pulmonary artery pressures were obtained at rest and during exercise both before and after intravenous administration of a vagus nerve blocking agent either in the form of 30 mg. of Pro-Banthine or 0.65 mg. of atropine sulfate. The specific data and the summary of the basic changes noted are presented in Tables IVA and IVB. In one instance a patient who had had a single episode of hemoptysis of unexplained etiology underwent this form of catheter study. Upon x-ray, bronchoscopic and pulmonary function studies no abnormalities were noted. He was found to have a maximum breathing capacity of 160 L. per minute and we have taken the liberty of considering him as having an essentially normal pulmonary vascular bed. The slight elevation in pulmonary artery pressure is thought to be explained by the mild systolic elevation in systemic blood pressure and a certain amount of anxiety present at the time of the procedure. It is noted that essentially normal systolic and diastolic pressures are recorded at rest with little or any change after exercise. After administration of a blocking agent there is no significant change in the systolic pulmonary artery pressure but there is a distinct increase in the diastolic component. In the one patient with pure bullous emphysema which consisted of a well-localized right upper lobe bulla, the remainder of the right lung appearing healthy at operation, there was every evidence of good pulmonary health [illegible] the findings were not dissimilar. It should be mentioned that no [illegible] of maximum breathing capacity or other abnormality on [illegible] function tests were found upon this patient. As can be [illegible]



SG PAP AT REST

PAP POST EXERCISE BEFORE BLOCK



SG PAP AT REST AFTER BLOCK

PAP POST EXERCISE AFTER BLOCK

Fig. [illegible].—Intraluminal pulmonary artery pressure readings obtained at cardiac catheterization showing decrease in pulmonary artery pressure and absence of marked increase after atropine block in a patient with Class III emphysema.

TABLE IVA CARDIAC CATHETER STUDIES (INTACT CHEST)
PULMONARY EMPHYSEMA, BULLOUS, MIXED BULLOUS AND CLASS III
GROUP I NO PREVIOUS OPERATION

PATIENT	TYPE	AGE	BLOOD PRESSURE	DRUG	PRESSURES BEFORE DRUG			PRESSURES AFTER DRUG			OTHER EFFECTS		COMMENT
					P A REST	P A EXER	R.V	P A REST	P A EXER	R V	O_2 UPTAKE	M B C	
D S*	Normal	30	140/90	Atropine	28/17	25/12	--	28/22	27/20	22/5	None	140 60 L/min	
H H	Bullous	46	130/80	Pro Banthine	22/12	31/15	--	25/12	33/15	37/4	--	160 L/min	No effect
J M	Mixed Bullous	49	124/84	Atropine	25/10	38/17	34/2	25/15	42/27	23/8	--	+35%	No effect
H G	Mixed Bullous	45	120/80	Atropine	20/10	37/25	--	30/20	37/26	25/0	None	None	Decrease Rise after exercise
G S	Class III	50	130/80	Atropine	36/18	50/27	25/2	25/13	29/15	17/0	--	%	Constant drop
S W	Class III		116/70	Pro Banthine	31/20	65/45	--	37/25	37/25	--	+40%	--	Blocked PAP Rise on exercise
A C	Class III		85/65	Atropine	60/37	75/60	55/6	35/25	50/37	35/10	+40%	--	Constant drop
T W †	Class III	41	142/100	Pro Banthine	40/19	45/23	--	39/19	45/30	40/30	--	None	No effect
J S ‡	Class III	48	115/65	Atropine	25/14	50/0	29/0	25/12	36/20	25/0	--	--	Blocked PAP Rise on exercise

PA=pulmonary artery
RV=right ventricle
PAP=pulmonary artery pressure
*Patient with normal pulmonary function (unexplained hemoptysis)
†Associated major bronchiectasis
‡Granuloma

TABLE IVB. CARDIAC CATHETER STUDIES: EFFECT OF BLOCKING AGENTS ON PULMONARY ARTERY PRESSURE
NORMAL—BULLOUS, MIXED, HYPERTROPHIC PULMONARY EMPHYSEMA (III)
GROUP I: NO PREVIOUS OPERATION

DISEASE OR TYPE	NUMBER OF PATIENTS	AGENT	PREBLOCK		POSTBLOCK	
			REST	EXERCISE	REST	EXERCISE
Normal (1)	1	Atropine	Normal	Normal	Constant diastolic	
Bullous	1	Pro-Banthine	Normal	-45%	Normal	-28%
Mixed	2	Atropine	Normal	-85% -55%	Normal	-23% -68%
III	2	Pro-Banthine	High systolic and diastolic with exercise		Systolic rise depressed Diastolic rise lost	
III	2	Atropine	High systolic and diastolic with exercise		Systolic rise blocked Diastolic rise blocked	
III plus bronchiectasis	1	Atropine	High	-13%	Diastolic raised further	

one goes over into the group of patients having either (a) mixed bullous and true hypertrophic emphysema (Fig. 3) or (b) the diffuse bilateral hypertrophic emphysema with major constant disability but not in a fixed stage (which we have taken the liberty of comparing with the Class III disability noted in cardiac patients), one immediately notes a different response to blocking agents (Fig. 4). Pressures which may be normal at rest rise significantly after exercise before block, and this abnormal rise after exercise is completely eradicated after the use of a blocking agent or is markedly depressed. We were particularly impressed with the constancy with which the diastolic component tended to drop after use of a blocking agent in patients with hypertrophic emphysema of a severity comparable to Class III. In contrast to this group of patients, the patients with Class IV emphysema, often referred to as "fixed" in type, showed essentially a constant elevation of pulmonary artery pressure at rest and often a very dramatic rise with exercise. There was little tendency for the blocking agent to eradicate the systolic rise after exercise, but a definite trend toward prevention of the postexercise diastolic rise was noted. We would like to clarify our definition of a "fixed" pulmonary emphysema patient as one in whom the disease is essentially uniform and diffuse bilaterally, with less than 2 cm. movement of either diaphragm; maximum breathing capacity is always 40 L. per minute or less and is not significantly benefited by any bronchodilating drug. This group of patients did present one definite difference in their response to exercise after drug when the time for return of the elevated pulmonary artery pressure to the resting base line was estimated. The results of this study are presented in Tables VA and VB. This group consists of 7 patients who had either true Class IV emphysema or emphysema bordering between a low Class III and a high Class IV. An elevation of pulmonary artery pressure was noted at rest and a markedly abnormal elevation to higher limits was noted on exercise. In these patients blocking agents often decreased the elevation of pulmonary artery pressure at rest down to normal limits, decreased the degree of diastolic rise after exercise, and often considerably depressed the rise in systolic pressure after exercise. The increased speed of return of the pressure levels to the resting base line after completion of exercise was recorded both in minutes and

TABLE VA CARDIAC CATHETER STUDIES (INTACT CHEST)
PULMONARY EMPHYSEMA (HYPERTROPHIC)—CLASS IV (FIXED)

PATIENT	AGE	BLOOD PRESSURE	DRUG	PRESSURES BEFORE DRUG			PRESSURES AFTER DRUG			OTHER EFFECTS		COMMENT
				P A REST	P A EXER	R V	P A REST	P A EXER	R.V	O UPTAKE	M B C	
M I	60	98/70	Pro Banthine	37/25	52/40	—	35/25	55/45	—	None	None	No effect
H D	39	95/65	Atropine	47/32	75/57	32/12	38/25	80/70	25/2	None	None	No effect
M B*	44	95/70	Atropine	49/30	75/55	42/10	45/12	82/62	42/2	None	None	No effect
C S†	39	100/70	Atropine	38/20	50/38	33/12	32/17	52/39	29/8	None	None	No effect

*Silicosis
†Asthma—bronchiectasis

TABLE VB CARDIAC CATHETER STUDIES (INTACT CHEST)
PULMONARY EMPHYSEMA (HYPERTROPHIC)—CLASS IV (FIXED)

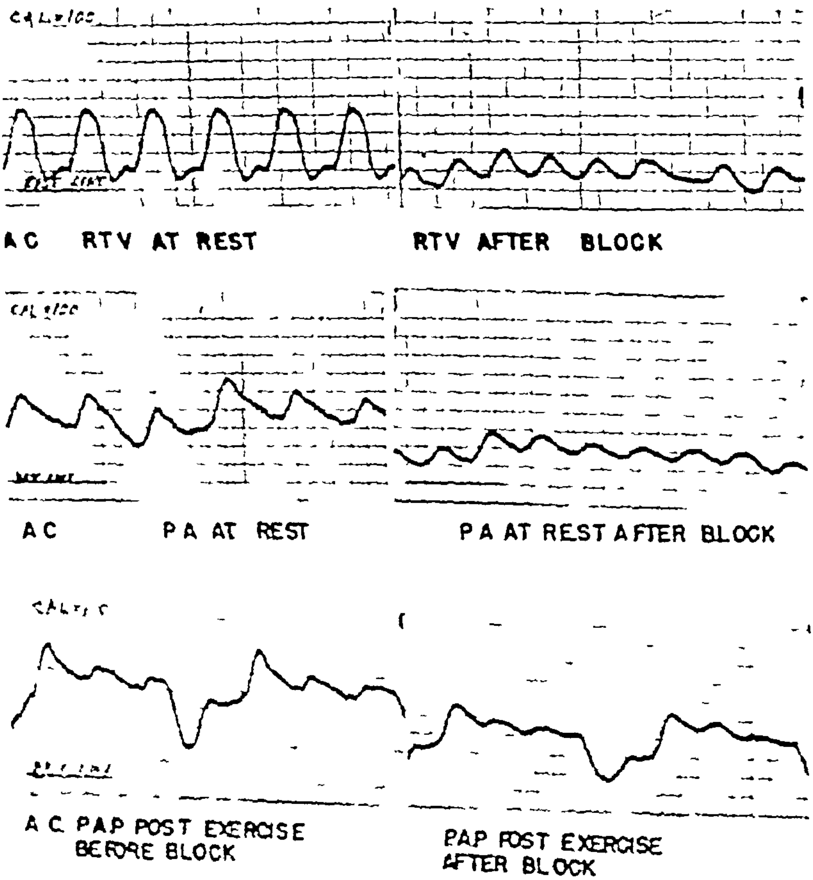
NUMBER OF PATIENTS	BLOCKING AGENTS	PRESSURE (REST)	PRESSURE (EXERCISE)	EFFECT
1	Pro Banthine	High	Higher	None
3	Atropine	High	Higher	None

TABLE VI. EFFECT OF ATROPINE UPON SPEED OF RETURN TO BASE LINE OF ELEVATED PULMONARY ARTERY PRESSURE—POSTEXERCISE (PULMONARY EMPHYSEMA)

PATIENT	TYPE	DIFF. REST	DIFF. EXERCISE	TIME RETURN	PER CENT SPEED RETURN
H. D.	IV	−9	−20	5 sec. less	50
M. L.	IV	−14	+7	9 sec. less	6
C. S.	IV	−6	−2	1 sec. less	16
A. C.	III	−25	−25	[illegible] sec. less	5
A. L.	III	−10	−12	5 sec. less	71
L. S.	III	0	−14	3 sec. less	60
H. G.	Pullou	+10	0	1 sec. less	25
Average		−8 mm Hg	−10 mm Hg	−4 Min.	−47%

in the percentage of increased rapidity of return. Figures quite definitely demonstrate an average increased speed of return of approximately 43 per cent faster recovery after administration of blocking agents (Table VI).

A small group of patients were studied who had undergone previous surgery directed toward the pulmonary autonomic nervous system. The results of



[illegible]

TABLE VIIA CARDIAC CATHETER STUDIES (INTACT CHEST) PULMONARY EMPHYSEMA (HYPERTROPHIC TYPE)—CLASS III
GROUP II—PREVIOUS DENERVATION

PATIENT	AGE	BLOOD PRES SURF	OPERATION	DRUG	PRESSURES BEFORE DRUG			PRESSURES AFTER DRUG			OTHER EFFECTS		COMMENT
					P A REST	P A EXER.	R.V	P A. REST	P A. EXER	R.V	O₂ UP TAKE	M B C	
A J	38	100/64	Bilateral sympathectomy	Atropine	35/10	52/25	—	25/12	40/29	—	—	+33 per cent	Constant drop
P A	50		Bilateral sympathectomy Right vagectomy	Pro Banthine	26/7	38/15	—	28/18	31/19	—	—	+16 per cent	Pulmonary artery block rise post exercise
C C R	59	138/95	Left vagectomy	Pro Banthine	37/12	85/55	44/2	42/22	70/50	48/2	+15 per cent*	20 per cent	Pulmonary artery block rise post exercise
H M	31	110/80	Right vagectomy	—	19/12	23/13	18/3	—	—	—	—	—	Minimal rise post exercise

*Increased O₂ uptake +25 per cent right lung 0 per cent left lung

TABLE VIIB CARDIAC CATHETER STUDIES (INTACT CHEST)
PULMONARY EMPHYSEMA (HYPERTROPHIC)—CLASS III
GROUP II—PREVIOUS DENERVATION

NUMBER OF PATIENTS	OPERATION	BLOCKING AGENT	PRESSURE PREBLOCK		PRESSURE POSTBLOCK	
			REST	EXERCISE	REST	EXERCISE
1	Bilateral sympathectomy	Atropine	High	−50 per cent	Normal	−14 per cent
1	Bilateral sympathectomy Unilateral vagotomy	Pro Banthine	Normal	−45 per cent	Normal	−10 per cent
1	Unilateral vagotomy	Pro Banthine	High	−125 per cent	High	−75 per cent
1	Unilateral vagotomy	No block	Normal	Normal	—	—

this study are noted in Tables VIIA and VIIB. The number of patients so studied is too limited to permit the drawing of final conclusions at this time but one is quite impressed with the classical Class III type of emphysematous response in the patient who had had bilateral upper dorsal sympathectomy from the level of the first through the sixth dorsal vertebra (Fig 5). The absence of sympathetic innervation of the lung in the presence of diffuse pulmonary emphysema still permitted a resting pulmonary artery pressure of a distinctly elevated type with a significant rise after exercise. Pharmacologic blocking of the vagus nerve components to the lung decreased the postexercise systolic and diastolic rise to a significant degree. A somewhat similar response is noted in the patient who had had a bilateral upper dorsal sympathectomy (the first through the seventh dorsal vertebra) with an associated unilateral pulmonary vagectomy. In the 2 patients with unilateral vagectomy instituted on the side of more intense hyper-

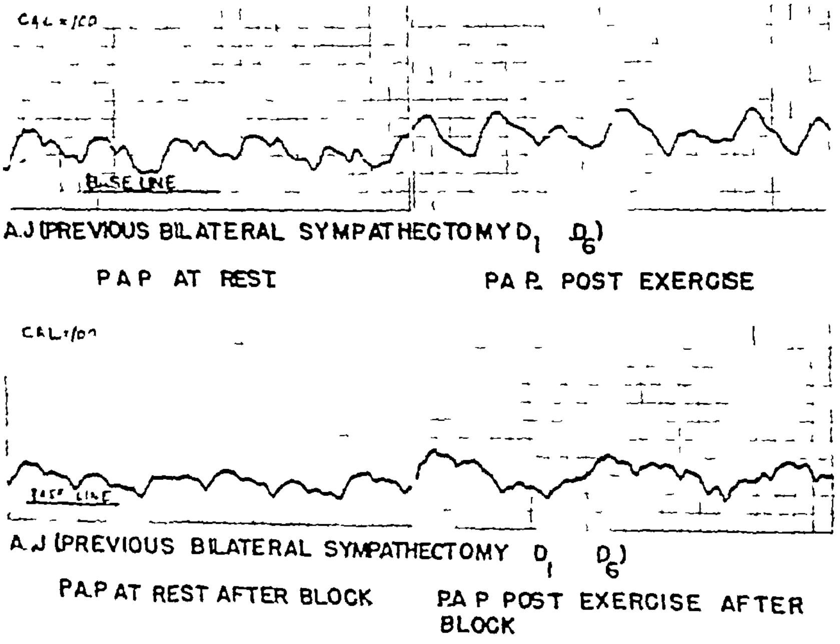


Fig 5.—Pulmonary artery pressure tracings at cardiac catheterization in a patient with Class III emphysema. She had previously had a bilateral dorsal sympathectomy (D 1 through D 6). Note pulmonary artery hypertension at rest and increase by exercise. Following [illegible] pulmonary hypertension was relieved and post exercise rise was decreased.

trophic emphysematous disease the findings suggest that this is probably a more physiologic approach to the disease entity under question. This type of preoperative catheter study has become a standard procedure in the surgical treatment of emphysema in this Clinic for the past year and we have abandoned all forms of dorsal sympathectomy as a component of operative procedures for emphysema. It is hoped that a sufficient number of patients will permit postoperative catheterization studies to allow more objective definitive comparison of these various surgical procedures in this disease.

TABLE VIIIA PULMONARY ARTERY DIRECT PRESSURE MEASUREMENTS (OPEN CHEST)
MISCELLANEOUS CARDIOVASCULAR LESIONS

PATIENT	AGE	BLOOD PRESSURE	DIAGNOSIS	TYPE OF BLOCK	CHANGES IN PULMONARY ARTERY PRESSURES										COMMENT
					VENT	P	5	VENT	P	10	VENT	P	15	OR 20	
W C	17	120/80	Tetrad	Direct	—	—	—	10/5	—	17/10	14/10	—	23/14	(20)	Increased PAP after block
I S	29	200/130	Coarctation	Direct	17/4	—	17/4	22/10	—	18/5	25/12	—	21/7	(15)	Fall in diastolic after block
H A	24	155/120	Coarctation	Direct	22/12	—	25/16	24/12	—	24/12	27/15	—	24/14	(15)	Fall in diastolic after block
L T A	5	88/70	Patent ductus arteriosus	Direct	27/22	—	28/19	28/21	—	—	26/21	—	33/22	(15)	Elevated PAP higher after block
W D	19	110/80	Patent ductus arteriosus	Direct	12/4	—	—	12/6	—	—	19/13	—	20/15	(20)	PAP normal
C E	55	144/110	RHD aortic stenosis, mitral insufficiency	Direct	22/18	—	22/18	22/18	—	25/22	24/20	—	25/22	(20)	No change
M A	35	108/80	Mitral stenosis	Direct	50/15	—	67/25	52/15	—	48/25	55/23	—	54/32	(20)	Rise in diastolic after block
T H	24	118/92	Mitral stenosis	Direct	40/24	—	43/24	43/24	—	43/24	41/24	—	43/26		No change

Vent. P—ventilatory pressures
RHD—rheumatic heart disease

Direct Pulmonary Artery Pressure Measurements (at Thoracotomy, Open Chest Wall).—

This method of study involving direct pressure measurements both of the pulmonary artery and of the pulmonary vein includes a considerably more diversified group of disease entities than the so called indirect or cardiac catheterization studies. It should be emphasized that the investigative studies were obtained prior to any handling of the lung, opening of the pericardium or other definitive surgery.

TABLE VIIIB. EFFECT OF VAGUS BLOCK ON PULMONARY ARTERY PRESSURES
DIRECT MEASUREMENT—OPEN CHEST
CARDIOVASCULAR LESIONS

NUMBER OF PATIENTS	DISEASE	METHOD OF BLOCK	EFFECT
1	Tetrad	Direct	Increase after block
2	Coarctations	Direct	Fall in diastolic
2	Patent ductus arteriosus	Direct	Further increase if elevated
1	Aortic stenosis and mitral insufficiency	Direct	None
2	Mitral stenosis	Direct	Rise in diastolic in one, none in other

a. Findings in Miscellaneous Cardiovascular Disease.—The data obtained in the study of various types of patients undergoing thoracotomy for various types of cardiovascular lesions are noted in Tables VIIIA and VIIIB. Only one tracing was recorded in the tetralogy of Fallot group since there was a tendency throughout this study to confine our studies to the adult patients. In this one instance it does appear that a significant increase in pulmonary artery pressure, both systolic and diastolic, was recorded after institution of left vagus nerve block. It is interesting to speculate upon the possible comparative benefit from such a block and the improved oxygenation often noted in this patient group after administration of morphine sulfate or Demerol. In the 2 patients with coarctation of the aorta the pulmonary artery pressure was found to be relatively low in proportion to the systemic blood pressure throughout the entire study. A fall in diastolic pressure with the ventilatory pressure at either 10 or 15 is seen to occur after block in both patients. Two patients with patent ductus arteriosus were examined, and in 1, where the pulmonary artery pressures were within normal limits prior to block, a similar condition persisted after block. In the other patient, in whom a pulmonary hypertension was found throughout the preblock studies, a further increase in the systolic pressure at high ventilatory pressures following direct vagus nerve block was manifested. One patient who had a hiatus hernia for which surgery was performed and who had moderately severe associated rheumatic heart disease with aortic stenosis and mitral insufficiency components showed no significant changes throughout the study. It is interesting to note that in this instance essentially normal pulmonary artery pressures were recorded throughout the study. In 2 patients [illegible] Class III mitral stenosis undergoing mitral commissurotomy a significant [illegible] pulmonary hypertension was present at all ventilatory pressures both [illegible] and after direct vagus nerve block. Although no change was noted in

TABLE IXA PULMONARY ARTERY DIRECT PRESSURE MEASUREMENT (OPEN CHEST) GRANULOMATOUS LESIONS

PATIENT	AGE	BLOOD PRESSURE	DISEASE	ASSOCIATED PULMONARY DISEASE	TYPE OF BLOCK	CHANGES IN PULMONARY ARTERY PRESSURE									COMMENT
						VENT	P	5	VENT	1	10	VENT	1	20	
A. P.*	15	160/100	Granuloma	Segmental emphysema	Atropine	20/0	→	16/0	22/2	→	18/4	27/16	→	21/9	Drop in PAP after block
W. T. M.	30	111/86	Granuloma	Segmental emphysema RUL—RML	Atropine	16/5	→	17/7	16/5	→	17/7	26/15	→	21/11	Drop in PAP after block at 20
M. Y.	12	100/70	Asbestosis granuloma	None	Atropine	11/5	→	11/8	18/8	→	19/12	20/9	→	22/15	Rise in diastolic

*Associated segmental areas hypertrophic emphysema.

TABLE IXB EFFECT OF VAGUS BLOCK ON PAP DIRECT MEASUREMENT—OPEN CHEST GRANULOMATOUS LESIONS

NUMBER OF PATIENTS	ASSOCIATED DISEASE	METHOD OF BLOCK	EFFECT
1	None	Atropine	Rise in diastolic
2	Emphysema	Atropine	Drop at 20 in both Drop at 5 and 10 in one

one of these patients; in the other patient a constant trend toward a higher diastolic pressure at all ventilatory pressures was recorded after institution of vagus nerve block. It is not felt that a sufficient number of patients of each type is included in this study group to make any definitive impressions. However, there are certainly interesting differences in the pre- and postblock pressure measurements in the 5 types of cardiovascular lesions indicated. It would appear that a disease which is characterized by high resting pulmonary artery pressure such as patent ductus arteriosus and mitral stenosis shows no tendency toward decrease in the systolic pressure after block while the diastolic pressure may increase. The apparently significant rise in pulmonary artery pressure after vagus nerve block in the single patient studied with pulmonary hypotension is of interest.

b. Granulomatous Lesions.—Studies were carried out upon 3 patients undergoing thoracotomy for peripheral granulomas. In 2 of these patients distinct areas of emphysematous change in the basilar segments of the lower lobe and the medial segment of the middle lobe were found to be present. Details of this study are shown in Table IXA with the summary of the basic changes produced portrayed in Table IXB. The patient with some asbestosis and a solitary peripheral granuloma and no emphysema presented essentially the findings expected to be seen in the normal lung. Specifically, a progressive increase in systolic pressure was noted with increased ventilatory pressure with a slight concomitant rise in diastolic pressure at these levels. The major change produced by intravenous atropine was again a rise in the diastolic pressure. In 2 patients with granulomas having associated emphysema the typical emphysema response (a drop in systolic and diastolic pressures at high ventilatory pressure levels) was noted after administration of the blocking agent.

c. Primary Pulmonary Carcinoma.—Tables XA and XB record the findings in a group of 3 patients undergoing thoracotomy for peripherally placed primary pulmonary carcinoma. In two instances when the remainder of the lung tissue appeared normal an essentially normal study was obtained with progressive rise in systolic and diastolic readings paralleling increases in ventilatory pressures prior to administration of blocking procedures, while after block there appeared to be a major rise in diastolic pressure and a tendency to increase in the systolic pressure. In the third patient, 72 years of age, with considerable arteriosclerosis and diffuse emphysema, a more classical emphysema type of recording was obtained.

d. Bronchiectasis.—(Tables XIA and XIB.) A group of 4 patients undergoing resectional procedures for bronchiectasis were studied by direct pulmonary artery pressure measurements. In [illegible] of these patients a remarkably static group of figures was obtained showing essentially no significant effect of the block except possibly for the lack of the expected rise in diastolic pressure noted in the normal response to atropine or vagus block. The fourth patient in this group who had advanced bilateral bronchiectasis and who had previously had the right middle and right lower lobes removed was found at the time of this resectional surgery to have a very significant degree of pulmonary hypertension. His findings both before and after block suggest a very fixed type

TABLE XA PULMONARY ARTERY DIRECT PRESSURE MEASUREMENTS (OPEN CHEST)
PRIMARY PULMONARY CARCINOMA

PATIENT	AGE	BLOOD PRESSURE	ASSOCIATED PULMONARY DISEASE	TUMOR SITE	TYPE OF BLOCK	CHANGES IN PULMONARY ARTERY PRESSURE			COMMENT
						VENT P 5	VENT P 10	VENT P 20	
J C	52	$\frac{104}{80}$	None	LUL	Direct vagus	$\frac{11}{8}-\frac{10}{6}$	$\frac{16}{6}-\frac{16}{10}$	$\frac{24}{10}-\frac{32}{24}$	Rise after block at 20
H S	52	$\frac{120}{80}$	None	Apex of LUL	Atropine	$\frac{15}{0}-\frac{17}{0}$	$\frac{15}{2}-\frac{23}{5}$	$\frac{27}{9}-\frac{37}{20}$	Rise after block at 20
W R	72	$\frac{170}{100}$	Arteriosclerosis and emphysema	LUL	Atropine	$\frac{27}{6}-\frac{14}{3}$	$\frac{26}{8}-\frac{17}{5}$	$\frac{33}{17}-\frac{31}{16}$	Drop after block

TABLE XB EFFECT OF VAGUS BLOCK ON PAP
DIRECT MEASUREMENT—OPEN CHEST
PRIMARY PULMONARY CARCINOMA

NUMBER OF PATIENTS	ASSOCIATED DISEASE	METHOD OF BLOCK	EFFECT
1	None	Direct	Rise after block at 20
1	None	Atropine	Rise after block at 20
1	None	Atropine	Constant drop after block

TABLE XIA PULMONARY ARTERY DIRECT PRESSURE (OPEN CHEST)
BRONCHIECTASIS

PATIENT	AGE	BLOOD PRESSURE	LOCATION OF DISEASE	TYPE OF BLOCK	CHANGES IN PULMONARY ARTERY PRESSURE			COMMENT
					VENT + 5	VENT + 10	VENT + 20	
J. H.	[illegible]	$\frac{132}{74}$	L. L. lobe and lingula Right M and L lobes removed previously	Direct vagus block	$\frac{11}{23}-\frac{11}{25}$	$\frac{10}{22}-\frac{13}{30}$	$\frac{15}{28}-\frac{11}{33}$	High basal PAP diastolic rise at 10 and 20
A. J.	29	$\frac{115}{80}$	Right middle and lower lobes	Direct vagus	$\frac{17}{7}-\frac{18}{8}$	$\frac{17}{7}-\frac{10}{9}$	$\frac{22}{12}-\frac{22}{12}$	No significant change
M. I.	47	$\frac{110}{80}$	Right middle lobe	Atropine	$\frac{15}{5}-\frac{15}{11}$*	$\frac{18}{7}-\frac{16}{12}$*	$\frac{22}{13}-\frac{19}{12}$	*Parallels rise in systemic pressure
F. N.	26	$\frac{107}{70}$	Left lower lobe	Direct vagus	$\frac{13}{7}-\frac{11}{8}$	-- --	$\frac{17}{11}-\frac{18}{14}$	No significant change

*A[illegible] hypertrophic type emphysema noted in basilar segments

TABLE XIB EFFECT OF VAGUS BLOCK ON PULMONARY ARTERY PRESSURE
DIRECT MEASUREMENT—OPEN CHEST
BRONCHIECTASIS

NUMBER OF PATIENTS	ASSOCIATED DISEASE	METHOD OF BLOCK	EFFECT
2	None	Direct	None
1	None	Atropine	None
1	Pulmonary hypertension	Direct	Diastolic rise at Vent P 10 + 20

TABLE XIIA PULMONARY ARTERY DIRECT PRESSURE MEASUREMENT (OPEN CHEST) PULMONARY EMPHYSEMA

PATIENT	AGE	BLOOD PRESSURE	CLASS	ASSOCIATED DISEASE	TYPE OF BLOCK	CHANGES IN PULMONARY ARTERY PRESSURE			COMMENT
						VENT P 5	VENT P 10	VENT P 20	
J S	18	115/65	III	None	Atropine	-- --	15/2 — 14/3	19/7 — 16/6	Drop after block
H G	15	120/80	Bullous	None	Vagotomy	-- --	-- --	22/11 — 21/8	No change
H H	42	136/90	Bullous mixed	None	Direct vagus	14/10 — 6/3	10/6 — 6/2	18/12 — 14/7	Drop after block
N T	48	170/120	III	Bronchiectasis RML	Direct vagus	25/9 — 18/8	22/8 — 16/10	29/15 — 26/15	Drop after block
J M	53	130/90	III*	None	Direct vagus	14/3 — 13/2	18/7 — 16/5	26/11 — 26/17	Systolic BP rose 40 mm/Hg during recordings
H M	44	120/90	III	None	Atropine	-- --	20/6 — 23/5.9	16.3/38 — 42.8/28	*Systolic* BP *rose* 15 mm/Hg during recordings
T W	44	142/100	III	Bronchiectasis	Direct vagus	20/11 — 15/6	22/10 — 15/7	27/13 — 19/10	Drop after block
J R	60	140/100	III	None	Direct vagus	15/7 — 12/7	17/8 — 13/7	21/10 — 15/6	Drop after block
W R	72	170/100	III	Bronchogenic carcinoma	Atropine	27/6 — 14/3	26/8 — 17/5	33/17 — 31/16	Drop after block
A E	45	160/100	III	Granuloma	Atropine	20/0 — 16/0	22/2 — 18/4	27/16 — 23/9	Drop after block
W T M	50	144/86	III	Granuloma	Atropine	16/5 — 17/7	16/5 — 17/7	26/15 — 21/14	Drop after block at 20

*Large apical bulla with severe hypertrophic emphysema rest of lung of pulmonary resistance with little change in the systolic pressure response to changes in ventilatory pressure and a suggestive significant rise in diastolic pressure when the ventilation reading was 10 and 20.

c. Pulmonary Emphysema.—Tables XIIA and XIIB designate the findings of direct pulmonary artery pressure studies on patients with different types of pulmonary emphysema. Again one should mention that these patients had had preoperative cardiac catheterization studies. The details of comparison of these two methods of study of the same patient will be presented in a later communication. At the present time our evidence indicates that there is a distinct parallel between the findings by the two methods. Pulmonary artery pressures tend to be distinctly lower in the lateral decubitus position under anesthesia than they are in the supine position in the conscious state.

TABLE XIIB. EFFECT OF VAGUS BLOCK ON PAP
DIRECT MEASUREMENT—OPEN CHEST
PULMONARY EMPHYSEMA

TYPE	NUMBER	METHOD OF BLOCK	NO EFFECT	DROP ONLY AT 20	CONSTANT DROP
Bullous	1	Direct	1	–	–
Mix I	1	Direct	–	–	1
III	4	Direct	–	–	4
III	5	Atropine	–	2	3

In the patient with pure bullous emphysema, a slight drop in diastolic pressure at high ventilatory pressures was noted after block. In the 1 patient with mixed bullous and hypertrophic emphysema a distinct tendency toward a drop in pressure after block was noted at all ventilatory pressure levels. In the third patient undergoing surgery for a large apical bulla but in whom an extreme degree of diffuse hypertrophic emphysema was present, the vagus block produced a relative drop in systolic pressure at all ventilatory pressure levels. Following direct vagus block the patient's systemic blood pressure increased 40 mm Hg and yet the pulmonary artery pressures after block were no higher than those taken prior to physiologic denervation. In the remaining 8 patients with Class III hypertrophic emphysema undergoing surgery consisting of resection of localized bronchiectasis plus vagotomy, lobectomy for carcinoma, subsegmental resection for granuloma, or vagectomy for hypertrophic emphysema there was a marked similarity of response. It would suggest that there is a classical pattern in hypertrophic emphysema such that following atropine or direct vagus nerve block the pulmonary artery pressure (both systolic and diastolic) shows a significant fall at most ventilatory pressure levels.

Effect of Vagus Block on Pulmonary Vein Pressure Using Direct Measurement Technique

To date 7 patients have undergone either isolated pulmonary vein studies or concomitant pulmonary vein and pulmonary artery pressure measurements. [illegible] lungs in 7 patients including various types of lesions are presented in Tables XIIIA and XIIIB. The early findings would suggest that little or no effect is obtained in such diseases as bronchiectasis, granuloma or [illegible] but a [illegible] in pulmonary venous pressure [illegible] in hypertrophic emphysema. The [illegible]

TABLE XIIIA. PULMONARY VEIN PRESSURE MEASUREMENTS (OPEN CHEST)

PATIENT	AGE	BLOOD PRESSURE	DISEASE	POSITION	TYPE OF BLOCK	CHANGE IN PULMONARY VEIN PRESSURES			COMMENT
						VENT P 5	VENT P 10	VENT P 20	
D C	22	$\frac{130}{95}$	Right M and L lobe bronchiectasis	Face down	Atropine sulfate	$\frac{14}{7}-\frac{15}{4}$	$\frac{17}{10}-\frac{16}{8}$	$\frac{21}{18}-\frac{24}{4}$	No significant effect
G R	26	$\frac{108}{70}$	Right M lobe bronchiectasis	Anterolateral	Direct vagus	$\frac{8}{3}-\frac{12}{8}$	$\frac{8}{6}-\frac{12}{10}$	$\frac{13}{9}-\frac{12}{9}$	Increased P at 5 and 10 after block
A K	34	98/60 80/62	Mitral stenosis	Anterolateral	Direct vagus	-- --	$\frac{17}{10}-\frac{18}{14}$	$\frac{23}{15}-\frac{27}{20}$	Some increase at 20 after block
H G	45	$\frac{120}{80}$	Emphysema	Lateral	Vagotomy	$\frac{+1}{-3}-\frac{-2}{-8}$	$\frac{+2}{-3}-\frac{0}{-4}$	$\frac{10}{5}-\frac{6}{2}$	Decreased PVP after block
J S	48	$\frac{160}{110}$	Emphysema	Lateral	Atropine	$\frac{+1}{-2}-\frac{-5}{-10}$	$\frac{-1}{-5}-\frac{-2.5}{-7.5}$	$\frac{1.5}{-1.5}-\frac{0}{-5}$	Decreased PVP after block
L T	50	$\frac{100}{80}$	Left lower lobe granuloma	Lateral	Direct vagus	$\frac{9}{4}-\frac{13}{6}$	$\frac{12}{7}-\frac{9}{5}$	$\frac{16}{9}-\frac{14}{9}$	No significant change
W K P	27	$\frac{106}{80}$	Granuloma and basilar segment emphysema	Lateral	Direct vagus	$\frac{3}{-2}-\frac{3}{-2}$	$\frac{3}{0}-\frac{4}{1}$	$\frac{7}{3}-\frac{14}{10}$	Increase at 20 after block

PVP—pulmonary vein pressures

TABLE XIIIB EFFECT OF VAGUS BLOCK ON PULMONARY VEIN PRESSURE DIRECT MEASUREMENT—OPEN CHEST MISCELLANEOUS DISEASES

NUMBER OF PATIENTS	DISEASE	METHOD OF BLOCK	EFFECT
1	Bronchiectasis	Atropine	None
1	Bronchiectasis	Direct	None
1	Granuloma	Direct	None
1	Granuloma and emphysema	Direct	None except increase at 20
1	Emphysema	Direct	Constant decrease
1	Emphysema	Atropine	Constant decrease
1	Mitral stenosis	Direct	None except increase at 20

tant pulmonary artery and vein direct pressure measurements is emphasized by this early pilot study. Concomitant studies in our respiratory function laboratory show an essentially constant major increase in oxygen uptake by emphysematous patients (Class III or above) after administration of such drugs as atropine, aminophylline, Pro-Banthine, Isuprel and Adrenalin. Certainly much of the detail of the pathologic physiology of pulmonary emphysema is not as yet adequately defined.

Production and Control of Vago-Vagal Type Syndrome by Regulation of Ventilatory Pressure.—Tables XIVA and XIVB outline a series of events which occurred in 6 patients (5 of whom were in the study group) of a total of 33 patients undergoing direct pressure measurement study. This constituted the single important essentially dangerous complication of this study. In 3 patients with mitral stenosis the effect of rise of ventilatory (inspiration) pressure from 10 to 20 mm Hg upon the blood pressure and pulse was recorded. In 2 of these patients concomitant pulmonary artery pressure readings were obtained. With the rise of ventilatory pressure to 20, constant drop in blood pressure and slowing of pulse were obtained. Direct vagal block could not alter this course of events but a return to normal status of such vital signs as blood pressure and pulse was obtained by resuming a ventilatory pressure of 10 mm Hg. An exactly similar situation obtained in 2 patients with pulmonary emphysema undergoing direct pressure measurements. In 1 of these intravenous atropine failed to block the reflex and in the other direct left vagus nerve injection with 1 per cent procaine failed to alter the physiologic disturbance. In both these patients the resumption of normal pulmonary artery pressure, systemic blood pressure and pulse obtained upon instituting a more physiologic ventilatory (inspiration) pressure, viz. 10 mm Hg. In the sixth patient noted on these tables who was not undergoing ventilatory pressure studies but undergoing mitral commissurotomy the precommissurotomy pressure readings in the pulmonary artery and in the left atrium revealed a bizarre disproportion of pressures. The intimation that this marked disproportion indicated a mechanical block to blood flow through the lung was not immediately appreciated and a severe drop in systemic blood pressure and slowing of the pulse ensued. Investigation revealed that the balloon of the endotracheal tube was overdistended and lapping over the end of the endotracheal airway. This was relieved and the operation proceeded. Following a classical commissurotomy the pulmonary artery pressure dropped to 22/10 while the left auricular pressure decreased to 8/6. It has not been our experience to see a pulmonary artery pressure of 70 decrease to less than 40 or 50 after commissurotomy on readings obtained at the operating table. We therefore infer that this patient's precommissurotomy pulmonary artery pressure was probably somewhere in the neighborhood of 80 mm Hg systolic until an obstructed airway intervened. It has long been our contention that manual and mechanical positive pressure as well as abnormally high ventilatory pressures prior to opening the thorax in patients with obstructions of either the right ventricular outflow tract or the left ventricular [illegible] is highly deleterious. The evidence presented above would tend [illegible]

TABLE XIVA PRODUCTION OF VAGO VAGAL TYPE SYNDROME BY HIGH VENTILATORY PRESSURE CORRECTION OF SYNDROME BY REDUCING PRESSURE ONLY

PATIENT	AGE	DISEASE	TEST	VENT P 10			VENT P 20			VENT P 10			COMMENTS
				BP	P	LAP	BP	P	LAP	BP	P	LAP	
W H	30	Mitral stenosis	Increase vent P	$\frac{120}{90}$	72	N R	$\frac{112}{80}$	72	N R	$\frac{122}{90}$	72	N R	No block
M A	35	Mitral stenosis	Increase vent P	$\frac{90}{60}$	100	$\frac{52}{14} \rightarrow \frac{48}{25}$	$\frac{70}{50}$	80	$\frac{55}{23} \rightarrow \frac{54}{32}$	$\frac{88}{60}$	$\frac{80}{100}$	$\frac{48}{25}$	BP unchanged PAP diastolic elevated by left vagus block
A K *	34	Mitral stenosis	Increase vent P	$\frac{98}{60}$	120	N R	$\frac{88}{60}$	96	N R	$\frac{98}{62}$	92	N R	BP effect unchanged by left vagus block
G C	40	Mitral stenosis	Partial respiratory obstruction	--	--	--	Obstruction $\frac{90}{60}$ 0	↓ 0	$\frac{70}{50}$	No obstruction $\frac{98}{60}$	80	$\frac{22}{10}$	During obstruction PAP 70/50 LAP 12/5 After obstruction PAP 22/10 LAP 8/6
T S †	48	Pulmonary emphysema	Increase vent P	$\frac{160}{110}$	80	$\frac{15}{2}$	$\frac{100}{60}$	100	$\frac{19}{7}$	$\frac{160}{110}$	120	$\frac{14}{3}$	Effect unchanged by atropine gr 1/100
T W	44	Pulmonary emphysema	Increase vent P	$\frac{160}{100}$	80	$\frac{22}{10} \rightarrow \frac{15}{7}$	$\frac{140}{90}$	60	$\frac{27}{13} \rightarrow \frac{19}{10}$	$\frac{160}{100}$	80	$\frac{20}{11} \rightarrow \frac{15}{6}$	Effect unchanged by direct block left vagus

P—Pulse

*With fall in BP the PVP rose both before and after block

†With fall in BP the PVP rose both before and after block

TABLE XIVB PRODUCTION OF VAGO-VAGAL TYPE SYNDROME BY HIGH VENTILATORY PRESSURES

NUMBER OF PATIENTS	DISEASE	EFFECT RISE VENT. P. 10 — 20	EFFECT DROP VENT. P. 20 — 10	EFFECT OF BLOCK
3	Mitral stenosis	1 High PAP unchanged 2 Constant BP drop 3 Pulse drop if high or normal	1 High PAP unchanged 2 Constant BP rise 3 Rise in pulse	None
2	Emphysema	1 PAP increased 2 BP dropped 3 Pulse slowed	1 PAP dropped 2 BP rose 3 Pulse speeded	None 1 Atropine 1 Direct
1	Mitral stenosis with respiratory obstruction	With obstruction and stenosis 1 PAP 70/50 LAP 12/5 2 BP severe drop 3 Pulse slow	Obstruction and stenosis relieved 1 PAP 22/10 LAP 8/6 2 BP normal 3 Pulse normal	

SUMMARY AND CONCLUSIONS

We have presented 2 groups of patients studied by different methods relative to the effect of vagus nerve blocking agents upon the pulmonary vascular dynamics in the presence of various cardiovascular and pulmonary diseases. Eighteen patients were studied by cardiac catheterization in the conscious state with the chest wall intact and physiologic vagus block produced by the use of either intravenous Pro-Banthine or atropine sulfate. In a second group of 33 patients direct pressure measurements were made upon the pulmonary artery, pulmonary vein, or both at the time of thoracotomy for various cardiovascular or pulmonary disease states. The statistical data obtained by this method of study have been presented, reviewed, and summarized.

We feel justified in drawing the following conclusions:

1. Studies upon the effect of various drugs which have known specific effects upon the autonomic nervous system on the pressure tracings obtained from the right heart and pulmonary artery in different cardiovascular and pulmonary diseases as well as in the normal human being should help to clarify our knowledge relative to the control of the heart, great vessels, and lung by the autonomic nervous system.

2. Intravascular pressure tracings obtained at the operating table under standardized conditions of anesthesia and ventilatory pressure constitute a new and useful tool for the investigation of the pathologic physiology of thoracic disease.

3. Such studies at the operating table can apparently be done without hazard to the patient if one is conscious of the capacity *of higher* ventilatory pressures to produce a vago-vagal type of reflex syndrome.

4. Study *of the effect of different* drugs or of the application of blocking agents to the sympathetic and parasympathetic nervous system can enhance the value of the direct pressure measurements made at the time of thoracotomy.

5. The pulmonary artery pressure in the patient with a normal cardiovascular pulmonary state should not rise after exercise but a rise in diastolic pressure is noted after pharmacologic vagus nerve block both at rest and after exercise.

6 Essentially similar findings were recorded for a patient with bullous emphysema and another with isolated peripheral granuloma, and in 2 patients with peripheral primary carcinoma in conjunction with normal appearing lung tissue

7 In patients with mixed bullous and hypertrophic emphysema, and patients with pure hypertrophic emphysema, Class III, the expected rise in pulmonary artery pressure after exercise was markedly depressed or blocked completely after injection of the pharmacologic vagus nerve blocking agent There was a distinct reduction in diastolic pressure in the pulmonary artery, both before and after exercise in emphysematous patients following institution of such a nerve block

8 In patients with so called "fixed" pulmonary emphysema, who had usually progressed to secondary pulmonary vascular changes (producing an irreversible pulmonary resistance) the vagus nerve block did not reduce the postexercise systolic pressure rise, nor was the diastolic pressure in the pulmonary artery depressed

9 However, in patients with Class IV emphysema, a more rapid return of an elevated postexercise pressure to the resting base line was obtained after the institution of pharmacologic block of the parasympathetic nervous system

10 Cardiac catheter studies upon a small group of patients having had previous surgery directed toward the pulmonary autonomic nervous system suggest that a harmful effect is obtained from dorsal sympathectomy and a beneficial one from pulmonary vagectomy, in patients with Class III pulmonary emphysema

11 Direct pulmonary artery pressure measurements upon a group of patients with miscellaneous cardiovascular disease suggest that vagus nerve block increases pulmonary artery pressure in tetralogy of Fallot, that the diastolic pressure may be depressed by higher ventilatory pressures in coarctation of the aorta, while in pre-existent pulmonary hypertension in patent ductus arteriosus this pressure may be further elevated by direct vagus nerve block The significant pulmonary hypertension noted in patients with mitral stenosis is essentially unaffected in its systolic component by variance in the ventilatory pressure before or after vagus nerve block However, in this group of patients, the diastolic pressure may increase at various ventilatory pressures after block

12 Patients with unilateral bronchiectasis demonstrated essentially a normal pattern of pressure measurement pulmonary vascular dynamics before and after vagus nerve block, except that the diastolic pressure tended to show no effect in response to administration of the blocking agents

One patient with advanced bilateral bronchiectasis and associated pulmonary hypertension showed the findings expected with a fixed type of pulmonary resistance such as is seen with pulmonary arteriosclerosis, pulmonary arteriolar sclerosis, or mitral stenosis Direct pressure measurement studies on patients with pulmonary emphysema showed little significant change in patients with pure bullous emphysema, but significant change in mixed bullous and hypertrophic or pure hypertrophic emphysema

13 The drop in systolic and diastolic pressure after atropine at average ventilatory pressures and high ventilatory pressures parallels the findings noted

in study of pulmonary artery pressures at rest and during exercise in conscious patients undergoing cardiac catheterization.

14. Too few studies on pulmonary venous pressure have been carried out to make definitive conclusions except that the initial pilot study promises that major information can be obtained from concomitant pulmonary artery and vein direct pressure measurements.

15. A vago-vagal type of syndrome with severe drop in systemic blood pressure, slowing of the pulse, and either elevation of the pulmonary artery pressure or maintenance of a high pulmonary artery pressure if already elevated can be produced by high ventilatory pressures. This vago-vagal type of syndrome persists despite administration of intravenous atropine or unilateral direct vagus nerve block. The changes are reversible by returning the ventilatory pressure to more physiologic limits.

16. Studies suggest that the pulmonary artery pressure found in health and disease was dependent upon: (a) right ventricular pressure and output, (b) the competence of the pulmonary valve, (c) the tone of the pulmonary arterial wall both as it may be affected by sclerosis and by spasm secondary to reflex autonomic nervous control, (d) abnormal systemic vascular to pulmonary vascular system shunts, (e) the pressure within the alveolus, and (f) the resistance presented by the inflow tract of the left heart (tone of the pulmonary vein wall, status of left auricle and mitral valve).

17. The vagus nerve appears to have the capacity to increase the pressure within the pulmonary artery by either contracture of the arterial wall or increasing the pressure within the alveolus by bronchospasm or both.

18. The capacity of vagal nerve blocking agents to produce: (a) increased ventilatory capacity, (b) decreased pulmonary artery pressure, and (c) concomitant increase in oxygen uptake at rest and during stress in pulmonary emphysema suggests that a pathologic degree of vagotonia is present in this disease.

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DISCUSSION

DR ELTON WATKINS JR, Boston, Mass—I have followed the very interesting work of Dr Abbott, Dr Sloan, Dr William Adams, and others in the forgotten field of lung circulation in various disease states The studies are difficult to do and more difficult to interpret Consequently, I would like to ask Dr Abbott one question, whether he has drawn any conclusions as to the site of action of these various types of autonomic nerve procedures The reason I ask this question is that many years ago Dr William F Hamilton showed that when he tinkered with the autonomic nervous system in experimental animals, there were changes in pulmonary artery pressure, but these changes resulted from the influence of the autonomic agent upon the systemic vascular bed As an injected autonomic drug passed through the lungs, very little change in pulmonary artery pressure occurred until the agent hit the peripheral circulation, when vasomotor changes occurred which shifted blood from the pulmonary vascular bed to the systemic vascular bed with a resulting decline in pulmonary artery pressure The reason I raise the point here is that, if the observed alterations in pulmonary artery pressure are the result of changes in the systemic vascular bed, the reduction of pulmonary artery pressure observed by Dr Abbott may be accompanied by deleterious peripheral circulatory effects of much greater significance than the pulmonary artery pressure changes

DR ABBOTT (Closing) —The question asked as to the exact action of these drugs, of course, is difficult There is some evidence to indicate that the action is upon neurogenic control of bronchial musculature I think we should emphasize the fact that the findings following drug action with effect upon the heart in the catheterized patient with the intact chest are similar to unilateral vagotomy, except not quite as complete as the unilateral vagotomy produced by direct injection of the isolated vagus nerve The persistence of action of these denervations is particularly striking in studying serial studies of patients before and after unilateral vagotomy The denervated lung which presented major obstruction to air flow on expiration prior to vagotomy expels air approximately twice as fast as the contralateral lung Thus, on fluoroscopic examination during forced expiration, a shifting of the mediastinum toward the side not operated upon is produced until contralateral vagotomy is performed This action, therefore, of denervation producing release of obstructive hypertonicity of the bronchial musculature is evident upon fluoroscopic examination Evidence is also obtained by the bronchoscope of the lack of contractural capacity of the bronchial musculature following pulmonary vagotomy The fact that investigations with the open chest show that high endobronchial ventilatory pressure produces alterations in pulmonary vascular dynamics only partially affected by denervation suggests to us that the action is motivated as follows The change in air pressure within the alveolus is a direct result of the tone of entering bronchiole into the atrium musculature plus the endobronchial ventilatory pressure The effect of this pressure within adjacent alveoli upon the interposed pulmonary vascular bed constitutes a petcock action, and thus, in part, controls the pressure within the pulmonary artery and vein Indeed, this facet of control of the lesser circulation by variance in intra alveolar pressure is reflected also into the greater circulation There is not time available to define the mechanisms existent to effect this intra alveolar pressure, but one may confidently state that the action of the vagus nerve in this regard is becoming increasingly evident

TEMPORARY UNILATERAL OCCLUSION OF THE PULMONARY ARTERY IN THE PREOPERATIVE EVALUATION OF THORACIC PATIENTS

A PRELIMINARY REPORT

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INTRODUCTION

THE ability of a patient with impaired cardiorespiratory function to tolerate pulmonary resection is difficult to evaluate. Satisfactory methods are available for the measurement of pulmonary function and the decrease in ventilatory function which will result from a pulmonary resection can be predicted. It is now recognized that inability of the cardiovascular system to compensate for a reduction in the pulmonary vascular bed following pulmonary resection may be as important as a reduction in ventilatory function in determining the outcome of operation. The desirability of studying the cardiovascular system in patients being considered for pulmonary resection has not been emphasized sufficiently despite deaths following operation which were due to pulmonary hypertension.[1, 2]

In 1951 Carlens, Hanson and Nordenström occluded one pulmonary artery temporarily with an inflatable balloon at the tip of a cardiac catheter. Extensive physiologic and angiographic studies of the pulmonary circulation employing this method were carried out.[3-5] Nemir, Stone, Mackrell and Hawthorne combined temporary occlusion of a pulmonary artery with occlusion of the bronchus to the same lung. These techniques have made it possible to produce the circulatory and ventilatory changes which might be expected to follow pulmonary resection as well as to evaluate the ability of the circulatory system to compensate for a reduction in the pulmonary vascular bed.

Studies of the circulatory changes following temporary unilateral occlusion of the pulmonary artery have been carried out by us in 18 patients being considered for pulmonary resection. Sixteen of the patients had carcinoma of the lung. One patient had bilateral obstructive emphysema due in part to bronchial compression by lymph nodes and the remaining patient had a localized inflammatory lesion.

METHODS

The patient was brought to the catheterization unit without breakfast after [illegible] with 75 mg. of Demerol. A double lumen Dotter-Lukas catheter

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[illegible]

with a distal occluding balloon and a proximal sampling orifice was passed through the left median basilic vein into the pulmonary artery of the involved lung The left brachial artery was punctured with a No 16 needle and a flexible wire stylet was passed through the needle into the artery The needle was withdrawn and a polyethylene catheter with an inside diameter of 0 047 inch and an outside diameter of 0 067 inch was passed over the stylet into the artery The stylet was then withdrawn The end of the catheter was obturated with a No 18 needle and a stopcock Arterial samples and pressures were measured through the stopcock The needle and stopcock were removed during the collection of samples for cardiac output in order to obtain maximum flow through the polyethylene tube

Measurements of pulmonary artery and brachial artery pressures were made with Statham strain gauges and recorded with a Sanborn Twin Viso Cardiette The zero reference level was 10 cm from the table top The electrocardiogram was monitored continuously Cardiac outputs were determined by the dye method after earlier attempts to measure cardiac output by the Fick principle yielded results which were not satisfactory For each cardiac output, 5 mg of T-1824 were injected into the pulmonary artery proximal to the balloon through the catheter Serial arterial samples were collected in tubes rotating on a kymograph Determinations of dye in the samples were made with a 6-A Coleman Junior Spectrophotometer Oxygen saturations were determined by the method of Van Slyke and Neill

Data were collected with the pulmonary artery patent, following unilateral occlusion of the pulmonary artery and during moderate exercise with occlusion of the pulmonary artery The average duration of pulmonary artery occlusion was forty-five minutes During each part of the study, the following determinations were made pulmonary artery and brachial artery pressures, oxygen saturations of pulmonary artery and brachial artery blood, and cardiac output The right or left pulmonary artery was occluded by the injection of 5 to 7 c c of 35 per cent Urokon into the balloon The balloon was filled under fluoroscopic control until it no longer moved in the pulsating pulmonary arterial stream and it began to conform to the outline of the pulmonary artery Data were obtained after the balloon had been inflated at least ten minutes Fifteen to twenty minutes later, while the balloon remained inflated, these data were collected during moderate exercise The exercise consisted of bicycling against arm resistance The exercise was continued for seven minutes and the data obtained during the last two minutes of exercise The position of the inflated balloon was checked fluoroscopically from minute to minute Maximum breathing capacity, total vital capacity, and one second timed vital capacity were obtained on each patient

RESULTS

In 18 patients, it was possible to occlude the pulmonary artery of the involved lung and to carry out studies on the systemic and pulmonary circulations Attempts to occlude the pulmonary artery were unsuccessful in 4 additional patients The catheter could not be passed into the pulmonary artery in 2 of these patients. The balloon burst as it was inflated in a third patient. The fourth patient had rectal bleeding from a recent sigmoidoscopy during the catheterization.

Insertion of the catheter and inflation of the balloon were only a little more difficult than manipulation of the catheter in a routine cardiac catheterization. Most of the patients' tolerated occlusion of one pulmonary artery well and had no symptoms during the period of occlusion. A few patients were subjectively short of breath but no patient was dyspneic. One patient noticed that his hearing and vision were more acute after the balloon was deflated although he had not been aware of any abnormality while the pulmonary artery was occluded.

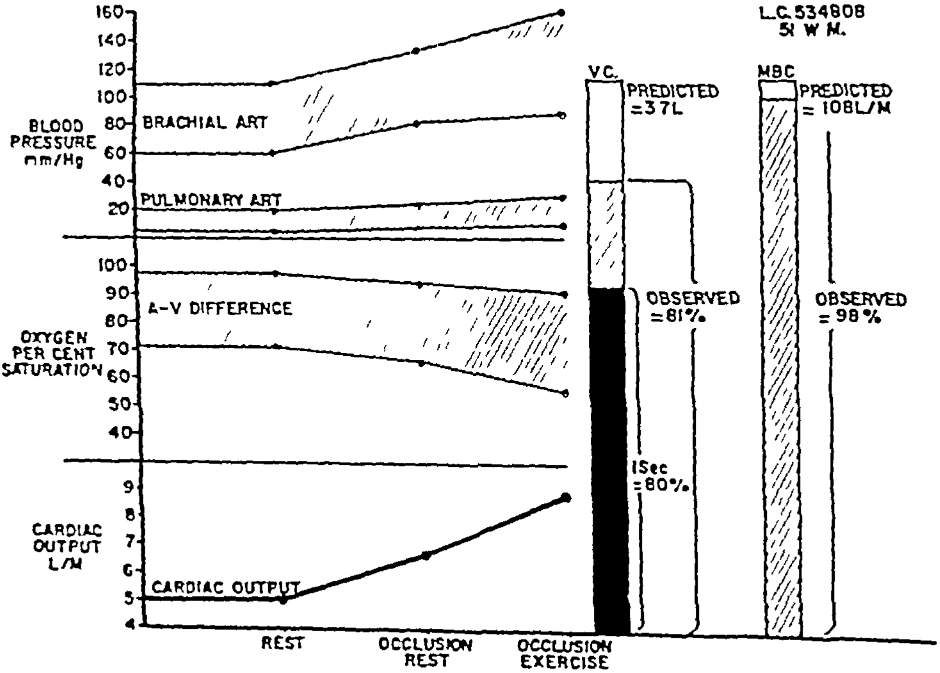

Fig 1.—[illegible] Normal response to temporary unilateral occlusion of the [illegible] pulmonary artery

The difficulties encountered in using the balloon catheter were related to the larger size and the more complex construction of the catheter. There was an increased incidence of venous thrombosis in the arm and early studies were followed by pyrogenic reactions. Rupture of the balloon during inflation in one patient was followed by a chill and fever but the patient had no symptoms at the time the balloon burst. In another patient the partially inflated balloon slipped into the main pulmonary artery. This was recognized quickly and the balloon was deflated. While the balloon was in the main [illegible] artery the patient's condition remained unchanged.

The [illegible] response to unilateral occlusion of the pulmonary artery [illegible]. The patient was a 51 year old white man in excellent [illegible] lung. There were metastases to the supraclavicular nodes Studies showed that pulmonary function was not significantly reduced With occlusion of the left pulmonary artery, there was a slight rise in the pulmonary artery and brachial artery pressures and a proportionate increase in the cardiac output and arteriovenous oxygen difference The brachial artery oxygen saturation remained normal While the left pulmonary artery was occluded, the patient was exercised The pulmonary artery pressure rose to 36/12 mm Hg and the brachial artery pressure to 152/76 mm Hg There was an additional increase in the arteriovenous oxygen difference and the cardiac output rose from a resting value of 5 1 L per minute to 8 9 L per minute The brachial artery oxygen saturation remained normal

An abnormal response to unilateral pulmonary artery occlusion was encountered in a 69-year-old man with carcinoma of the left lung and systemic hypertension The data are charted in Fig 2 There was a moderate reduction in pulmonary function, although the timed vital capacity was within normal limits The pulmonary artery pressure was 20/6 mm Hg at rest

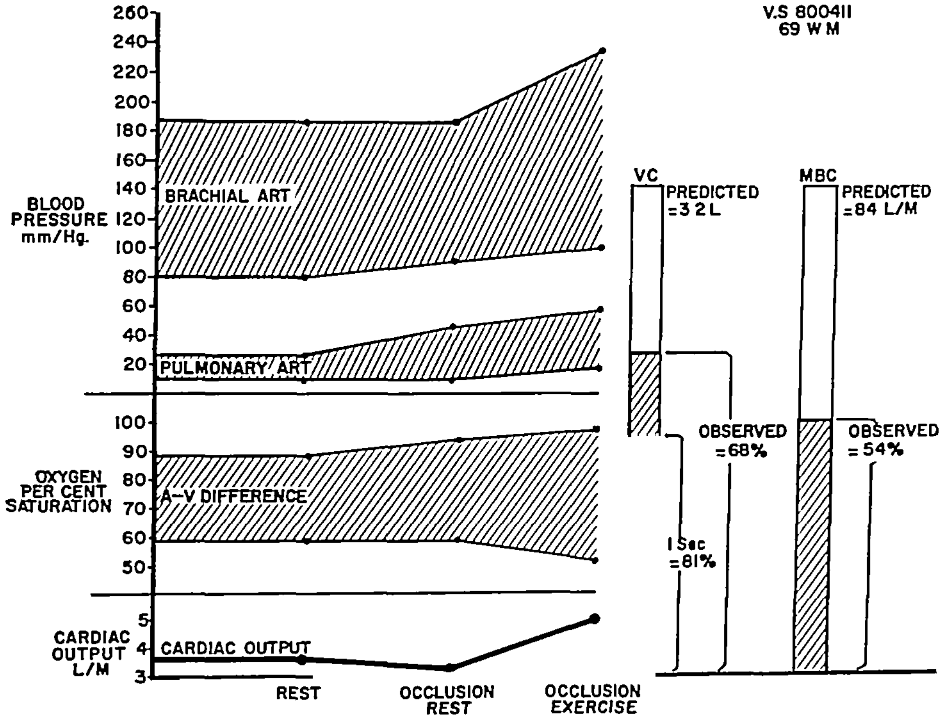

Fig 2.—Left pulmonary artery occlusion Abnormal response to temporary unilateral occlusion of the pulmonary artery in a patient with impaired cardiovascular function

It rose to 26/14 mm Hg following occlusion of the left pulmonary artery With exercise and occlusion of the pulmonary artery, the pulmonary artery pressure rose to 48/14 mm Hg This rise in pressure was not accompanied by a proportionate increase in the cardiac output but there was a marked increase in the arteriovenous oxygen difference With exercise, the brachial artery oxygen saturation rose from 89 per cent to 96 per cent

The rise in pulmonary artery pressure with pulmonary artery occlusion and exercise the increase in the arteriovenous oxygen difference and the slight rise in the cardiac output were believed to represent an inability to compensate for a reduction in the pulmonary vascular bed and an inability to increase the cardiac output with effort

A left upper lobectomy was performed The patient did well for a few days but then became increasingly cyanotic and dyspneic He died on the eleventh postoperative day Death was believed to be due to progressive cardiorespiratory insufficiency The post-mortem examination showed pulmonary emphysema and far advanced generalized arteriosclerosis and arteriosclerotic heart disease with cardiomegaly

The cardiovascular response of a second patient to occlusion of the right pulmonary artery was similar to that just described This 65 year old white man with a history of asthma had a carcinoma of the right lung The patient s maximum breathing capacity was 68 per cent of the predicted normal value and his vital capacity was 92 per cent of the predicted normal value A right upper lobectomy was performed The patient developed pulmonary edema in the immediate postoperative period He improved and his condition was satisfactory for several days A bronchial leak required the reinsertion of a thoracotomy tube The patient became increasingly cyanotic and dyspneic He died seventeen days following operation Permission for a post-mortem examination was not obtained

These 2 patients had pulmonary function studies which were sufficiently good to have permitted a lobectomy to be done The death of each patient was due in part to the inability of his cardiovascular system to compensate for the changes produced by operation

The findings in a 49 year old white man with carcinoma of the right lung are presented in Fig 3 Although the vital capacity was 90 per cent of normal the one second timed vital capacity and the maximum breathing capacity were reduced to 50 per cent of the predicted normal values With occlusion of the right pulmonary artery and exercise the cardiac output doubled without a marked increase in the pulmonary artery pressure A right pneumonectomy was done and the patient recovered uneventfully despite the decrease in pulmonary function The ability of the patient s cardiovascular system to compensate for a reduction in the pulmonary vascular bed may have contributed to the successful outcome

None of the 18 patients studied had significant pulmonary hypertension at rest Evidence of cardiovascular insufficiency and pulmonary hypertension was most striking when unilateral pulmonary artery occlusion was combined with exercise A marked rise in pulmonary artery pressure, a greater increase in the arteriovenous oxygen difference, and a failure to increase the cardiac output indicated that the patient might not tolerate a pulmonary resection The findings suggestive of cardiovascular insufficiency did not uniformly parallel reduction in ventilatory function

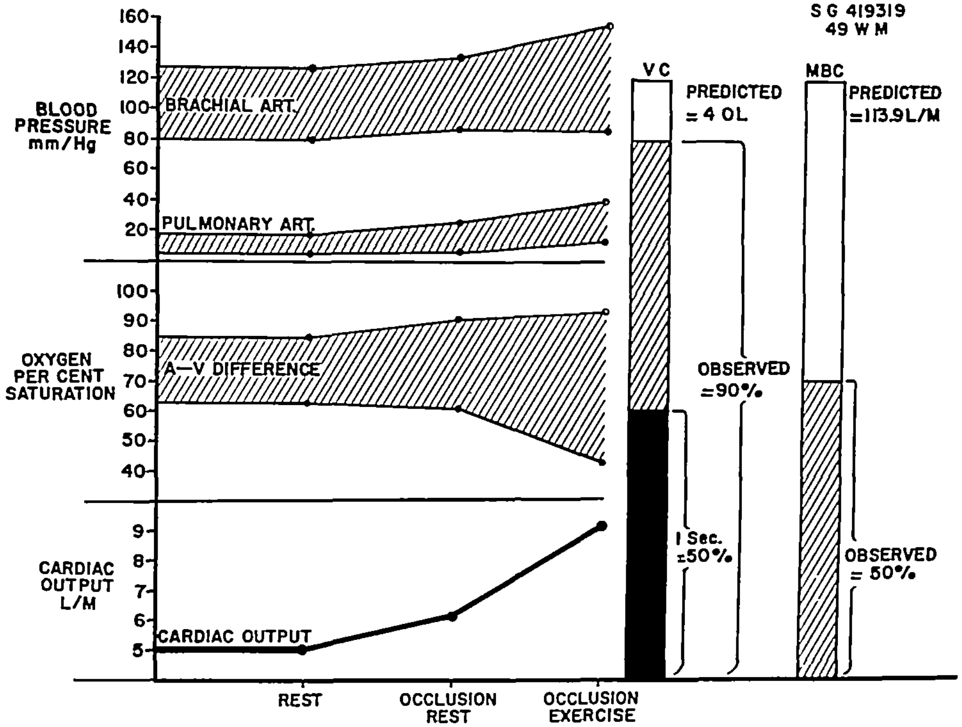

Fig 3 —Right pulmonary artery occlusion Normal response to temporary unilateral occlusion of the pulmonary artery in a patient with decreased pulmonary function

SUMMARY

1 Temporary occlusion of the right or left pulmonary artery with a balloon catheter was carried out successfully in 18 patients

2 Unilateral occlusion of the pulmonary artery combined with exercise is a valuable method for studying the cardiovascular response to reduction in the pulmonary vascular bed

3 In patients with impaired cardiovascular function, there is a marked rise in the pulmonary artery pressure, an abnormal increase in the arteriovenous oxygen difference, and a failure of the cardiac output to increase significantly when pulmonary artery occlusion is combined with exercise

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CORONARY PERFUSION FOR LONGER PERIODS OF CARDIAC OCCLUSION UNDER HYPOTHERMIA*

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INTRODUCTION

CARDIAC occlusion under general hypothermia is a satisfactory method for performing operations of relatively short duration on the open heart Despite the fact that Lewis used hypothermia to close successfully the first cardiac septal defect under direct vision in 1952, hypothermia has been utilized principally for juxtacardiac surgery[1, 3] Limited experience is reported with extension of low body temperature to intracardiac procedures more complicated than correction of atrial septal defects[4, 5] Factors responsible for this limitation are related primarily to failure of the heart after prolonged periods of occlusion Hypothermia seems to give less protection to the heart than to other important body systems probably because the heart extracts more oxygen from the blood than any other organ[6] The period of cardiac occlusion from which recovery will regularly occur should be increased by adding coronary perfusion to supply the heart with oxygen

Hypothermia not only protects the heart inadequately during periods of prolonged occlusion, but it also stimulates a relatively high incidence of ventricular fibrillation In one-third of our clinical cases, ventricular fibrillation occurred at some time during the procedure, in only one was defibrillation unsuccessful Swan[7] reported 100 per cent ventricular fibrillation in hypothermic dogs subjected to right ventriculotomy if neither Prostigmin nor acetylcholine was used to perfuse the heart prior to cardiotomy Although defibrillation of the cold heart is not difficult, it is not enough to obtain survival if the incidence of ventricular fibrillation has been significant

The design of these experiments with coronary perfusion was twofold to prolong the period during which intracardiac surgery could be performed at safe levels of hypothermia, and to avert ventricular fibrillation by oxygenating the myocardium

METHODS OF CORONARY PERFUSION IN THE DOG

The term indirect coronary perfusion is used to distinguish this technique from direct cannulation of the coronary arteries All experiments were performed on adult dogs weighing from 25 to 80 pounds, anesthetized with pentobarbital sodium, and cooled to 25° C Further details of cooling have been given elsewhere[8]

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Fig. 1 illustrates the anatomic considerations. Right thoracotomy is carried out through the fourth intercostal space. The azygos vein is divided between ligatures permitting mobilization of the superior vena cava. Elevation of the superior vena cava provides entrance into the posterior pericardium. A tourniquet for use during perfusion is loosely placed around the brachiocephalic artery at its junction with the aortic arch. The arch of the aorta is then cleared only enough to permit complete obstruction with a noncrushing clamp at a point between the brachiocephalic and left subclavian arteries. While the aortic clamp is momentarily closed, a No. 10 or 12 F. Pardee oxygen catheter is threaded into the ascending aorta via the right

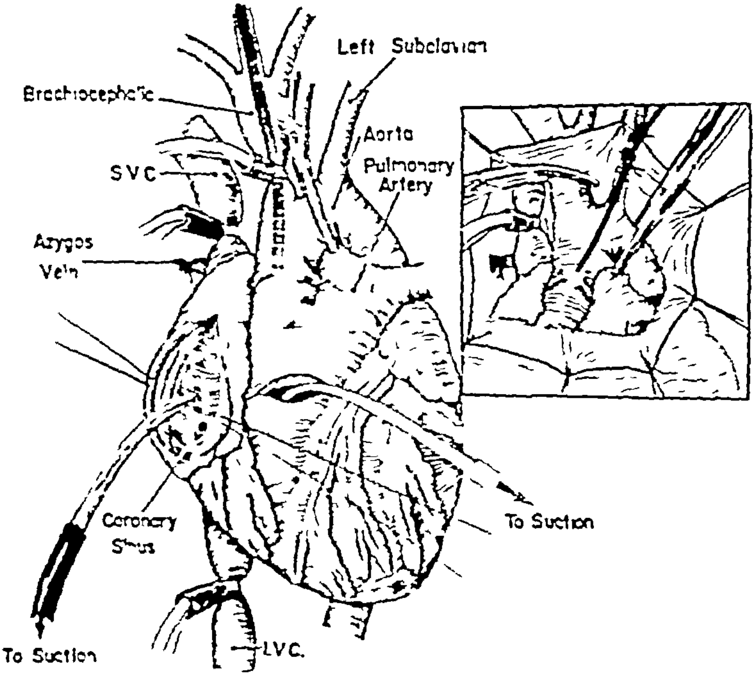

Fig. 1.—Technique of coronary perfusion.

coronary sinus, the anterior coronary veins, and the Thebesian veins, it was aspirated through either a cardiotomy or an incision in the pulmonary artery

The composition of the perfusate was altered from series to series and will be discussed separately The flow rate was varied from 50 to 85 c c per minute Pressures were measured in some experiments, and the range was from 25 to 85 mm Hg Pressures were related more to the strength of the heartbeat than to the flow rate at these slow rates of flow

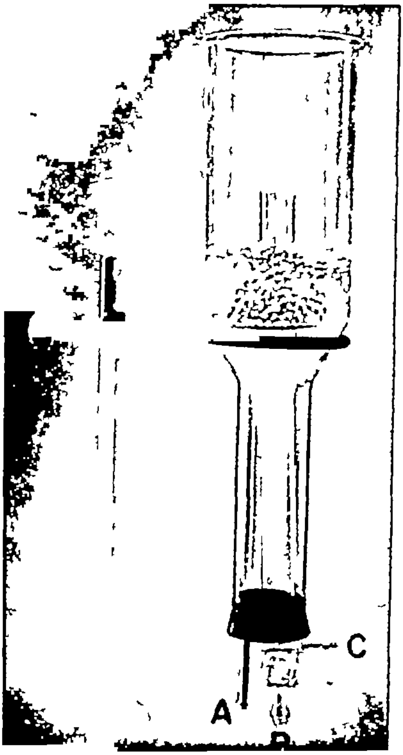

Fig 2 —*A*, Outlet for blood from oxygenator *B* Oxygen inlet *C* Inlet for blood entering oxygenator

INITIAL STUDY

At first, we thought it was necessary to obtain arterial levels of oxygen saturation in the blood to be used as perfusate For this reason a modification of the Clark-Gollan gas dispersion apparatus was constructed[9] This simple, bubble-type oxygenator, consisting of two concentrically placed glass cylinders, is seen in Fig 2 Oxygen introduced through a sintered glass disc in the bottom of the inner cylinder bubbled blood into the outer tube or reservoir ready for coronary perfusion Glass beads coated with Antifoam A* were suspended in the outer tube by means of a stainless steel sieve Blood was recirculated through the oxygenator after it had been aspirated from the heart so that the entire perfusion could easily be done with 500 c c of blood

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*Dow Corning Corp Midland Mich

In the first two experiments citrated blood was used but ventricular fibrillation occurred almost as soon as the perfusion was started. Cookson and co-workers[11] have called attention to this phenomenon. All further perfusions were performed with heparinized blood (20 mg. of heparin per 500 c.c. of blood).

Table I summarizes the results of the initial study. Immediate survival indicates that the animal regained normal temperature and was alive a minimum of 6 hours postoperatively. Late survival denotes that the dog was living at least one week following the procedure. Dogs were sacrificed after the one week period in order to obtain blood for use in future studies.

TABLE I. CORONARY PERFUSION WITH OXYGENATOR BLOOD
INITIAL STUDY

CARDIAC APPROACH	NUMBER	IMMEDIATE SURVIVAL	LATE SURVIVAL	VENTRICULAR FIBRILLATION	TIME (MIN.)
Pulmonary arteriotomy	3	3	3	1	20
Right atriotomy	10	10	3	2	3 for 30
Right ventriculotomy	3	3	1	2	7 for 20
Total	16	16	7	5	20

The circulation was occluded in 6 dogs for 30 minutes and in 10 dogs for 20 minutes. Two of the former group had neurological impairment but none of the latter group did. In fact, neurological deficit was never observed in any dog with circulatory occlusion for 20 minutes at 25° C.

Our attention was not specifically attracted to bleeding difficulties although four deaths were attributed to hemorrhage complicated in one instance by empyema and atrial necrosis with perforation.

CLINICAL TRIAL

The perfect record of immediate survival and the relatively low incidence of ventricular fibrillation persuaded us to use coronary perfusion with the oxygenator clinically for the closure of two atrial septal defects under hypothermia.

Bleeding appeared to come from many small sources rather than from any single site Following the second operation, chest drainage diminished slowly and the patient recovered fully

The flow rate for each case was close to 100 c c per minute Blood was not recirculated through the oxygenator The hearts were pink and apparently well oxygenated during the perfusions Cannulation was done through the left subclavian artery Although both hearts fibrillated, the ease of defibrillation was remarkable Before further clinical application could be advocated, however, a more critical laboratory evaluation was necessary

SECOND STUDY

In the second series of animal experiments, we were seeking in particular any characteristics of the technique which might explain the bleeding tendency which had appeared clinically Both the oxygenator and the technique were under scrutiny To make the experiments more similar to the clinical situation coronary drainage was aspirated and discarded rather than recirculated through the oxygenator The animals were carefully followed postoperatively and given transfusions when it was indicated Table II outlines the results obtained in 7 consecutive dogs with 20 minutes of circulatory occlusion and coronary perfusion

TABLE II CORONARY PERFUSION WITH OXYGENATOR BLOOD
SECOND STUDY

CARDIAC APPROACH	NUMBER	IMMEDIATE SURVIVAL	LATE SURVIVAL	VENTRICULAR FIBRILLATION	TIME (MIN)	WHOLE BLOOD TRANSFUSION
Right atriotomy	7	7	7	0	20	4

Transfusions were necessary in 4 of the 7 animals, and 1 dog received 800 c c of blood to replace loss from the chest cavity Protamine, which was given in each case (50 to 150 mg), seemed to have little effect on the persistence of chest drainage Bleeding eventually subsided in all experimental cases, and the late survival rate of 100 per cent was undoubtedly the result of intensified postoperative care

Clotting factors were checked as well as platelet count, plasma hemoglobin, hydrogen ion concentration (pH), and oxygen content on blood entering and leaving the oxygenator Samples of coronary drainage were also analyzed for oxygen saturation to ascertain roughly the myocardial oxygen consumption In general, there was a small increase in the clotting time after perfusion, but no increase in prothrombin time was detected in any of the 3 dogs whose prothrombin time was determined The entire laboratory analysis of this series is given in Table III Platelet counts were insignificantly diminished by the action of the oxygenator Plasma hemoglobin was always higher in blood coming from the oxygenator but never greater than 147 mg per cent The pH shift was toward the alkaline side with 7 63 the most alkaline pH of blood leaving the machine Oxygen contents were uniformly elevated to approximately 20 volumes per cent by the oxygenator depending on the hemoglobin concentration Oxygen saturation of the coronary drainage averaged 5 4 volumes per cent less than the perfusate, but the range was wide depending on the cardiac activity when the sample was taken

TABLE III. CORONARY PERFUSION WITH OXYGENATOR BLOOD
LABORATORY RESULTS OF SECOND STUDY

	Dog No. 1		2		3		4		5		6		7	
	A*	B	A	B	A	B	A	B	A	B	A	B	A	B
Oxygen content, vol %	8.1	10.7	11.2	19.9	10.7	22.5	11.1	22.3	11.2	21.0	15.1	20.0	11.15	10.88
Hb (Gm %)		—	11.6	11.0	15.0	15.0	14.7	11.6	11.1	12.8	14.1	11.1	12.0	12.1
Plasma Hgb, mg %	18	30	0	20	10	—	67	117	38	13	18	58	6	23
Platelets in 1000's	110	112	270	230	224	292	221	161	151	152	138	112	80	110
pH	7.43	7.52	7.41	7.53	7.41	7.49	7.35	7.61	7.41	7.53	7.28	7.51	7.30	7.50
Oxygen content of coronary drain, vol %	10.9		10.8		20.1		15.2		10.1		10.1		10.18	
Clotting time before perfusion	—		Lee White 11 min		Lee White 11 min		capillary 5 min		capillary 5 min		capillary 1.5 min		capillary 1.5 min	
Clotting time after perfusion	—		Lee White 15 min		Lee White 15 min		capillary 14.5 min		capillary 12 min		capillary 5 min		capillary 1.5 min	
Prothrombin time after perfusion	—		No increase		No increase		No increase		—		—		—	
Flow rate, cc per min	80		80		80		50		50		50		85	

*A Blood to oxygenator
B Blood from oxygenator

Very little could be found to explain the postperfusion bleeding encountered clinically and in some of the dogs. Elevation of clotting time seemed to depend on how carefully one aspirated the perfusate thus preventing escape into the pulmonary circuit. Neither clinical case manifested any increase in clotting time. The exact cause of the bleeding tendency remained obscure although the glass composition of the oxygenator may have played a part.[11] Apparently cardiac perfusion itself was enough to transmit the hemorrhagic diathesis to the animal since very little perfusate was permitted to enter the circulation.

CORONARY PERFUSION WITH VENOUS BLOOD

Because of the low oxygen utilization by the empty, hypothermic heart, it was felt that blood with venous levels of oxygen saturation would maintain a reasonable degree of myocardial oxygenation during perfusion. Table IV describes the results of 10 consecutive coronary perfusions with venous blood.

TABLE IV. CORONARY PERFUSION WITH VENOUS BLOOD

CARDIAC APPROACH	NUMBER	IMMEDIATE SURVIVAL	LATE SURVIVAL	VENTRICULAR FIBRILLATION	TIME (MIN.)	WHOLE BLOOD TRANSFUSION
Right atriotomy	5	5	5	0	20	0
Right ventriculotomy	5	5	5	2	20	0
Total	10	10	10	2		0

No blood transfusions were needed. All animals survived indefinitely after cardiac occlusion for 20 minutes at 25° C. Ventricular fibrillation occurred in only 2 animals. Venous blood was drawn from donor animals by means of a femoral vein catheter. Flow rates were always 50 c.c. per minute so that two 500 c.c. bottles of heparinized blood were sufficient for the 20 minutes of perfusion. Oxygen contents were determined on each bottle of blood before perfusion and on the coronary drainage; the values are listed in Table V.

TABLE V. CORONARY PERFUSION WITH VENOUS BLOOD
OXYGEN CONTENT VOLUME PER CENT

	DOG NO.									
	1	2	3	4	5	6	7	8	9	10
Bottle 1										
Before perfusion	8.56	11.08	10.20	11.61	11.40	5.81	9.64	10.42	9.38	6.93
Coronary drainage	2.33	7.42	3.90	6.25	11.19	2.54	3.68	1.94	5.72	2.01
Bottle 2										
Before perfusion	9.21	10.99	4.00	10.87	12.19	7.45	11.34	16.31	15.78	12.61
Coronary drainage	4.59	7.95	0.88	4.82	7.71	5.21	7.98	9.14	11.25	8.17

The lowest oxygen content of any perfusate was 4 volumes per cent with the heart consuming all but 0.88 volume per cent of the available oxygen. Coronary drainage averaged 4.4 volumes per cent less in oxygen content than the perfusate. In 1 dog ventricular fibrillation occurred as the catheter was threaded into the aorta; defibrillation was quickly done after which the animal withstood 20 minutes of cardiac occlusion and right ventriculotomy without relapse into fibrillation.

DISCUSSION

The fact that the heart extracts more oxygen from the blood than any other organ in the body is the basis for attempting to prolong, by means of coronary perfusion the period of cardiac occlusion from which animals consistently recover. By protecting the heart with oxygen brain tolerance to circulatory interruption becomes the factor which determines the safe period of cardiac occlusion under hypothermia. Full advantage of the time allowed by resistance of the nervous system to hypoxia at low temperatures has not previously been taken because of failure of the heart to survive. Perfusing the heart with blood containing even venous levels of oxygen permits 20 minutes of occlusion in the dog at 25° C. without evidence of neurological damage.

The best results with hypothermia in experimental surgery are obtained at temperatures well above 20° C. Bigelow and associates[12] had only 6 final survivors in 39 dogs with 15 minutes of cardiac occlusion at 20° C. Our experiments indicate that prolonged cardiac occlusion is possible at a safe level of hypothermia if the myocardium is oxygenated. Bigelow has maintained that complicated intracardiac surgery necessitates 20 minutes of circulatory occlusion at 20° C., a temperature too dangerous for clinical use.[17] We feel that the repair of such conditions as interventricular septal defects can be done within the time permitted by safe levels of hypothermia particularly if the heart is protected by coronary perfusion.

Cookson and Costas-Durieux[14] have stated that cardiac perfusion pressures should be in the range of 70 mm. Hg to prevent coronary air embolism and that a nonpulsatile flow is necessary to avoid aortic regurgitation. Despite these measures, 2 of his 11 dogs suffered coronary air embolism. Momentary supravalvular occlusion of the aorta to provide a dry operative field during full body perfusions has not predisposed to coronary air embolism in the presence of ventricular septal defects.[1] The necessity for a nonpulsatile flow at a relatively high pressure probably does not exist when the heart is empty and the pressures generated by cardiac action decreased. The principal danger of coronary air embolism is incomplete evacuation of air from the heart before closure of the defect and the cardiotomy.

Ventricular fibrillation occurred in only 2 of 17 consecutive experiments. While coronary perfusion did not preclude ventricular fibrillation, the incidence was well within an acceptable range. Dogs at normal temperatures frequently respond to right ventriculotomy by developing fibrillation; hence abolition of ventricular fibrillation in any series of cardiotomies is rather unlikely.

SUMMARY AND CONCLUSIONS

1. Coronary perfusion can prolong the period of cardiac occlusion under hypothermia.

2. At 25° C. the central nervous system can tolerate 20 minutes of circulatory interruption without evident neurological damage.

3. A bubble type oxygenator made of glass produces bleeding even when nearly all perfusate is aspirated from the heart.

4. Coronary perfusion with venous blood at a flow rate of 50 c.c. per minute is satisfactory for maintaining an acceptable degree of myocardial [illegible]

[illegible]

5 Protection from ventricular fibrillation is demonstrated by the consecutive, long-term survival of 12 dogs undergoing 20 minutes of cardiac occlusion at 25° C and right atriotomy without ventricular fibrillation

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DISCUSSION

DR OSLER ABBOTT, Emory University, Ga —I believe we should place some emphasis on the following problem which was presented to us rather dramatically in a patient This was a patient with a thoracic aortic aneurysm wherein preoperative studies could not define whether there was need for resection of a segment of the aorta with temporary occlusion of aortic blood flow or just an amputation of the sac without aortic occlusion At operation aortic occlusion proved necessary Hypothermia was produced by externally circulating blood utilizing a Sigmamotor pump, the tubing of which was imbedded in coils of ice The tubes had been primed with heparin and the patient had a total dosage of 25 mg of this drug The aorta was occluded just distal to the left subclavian artery, and citrated blood replacement was given The hypothermia and aortic occlusion produced a major degree of hypotension within the liver bed A clinical syndrome, of irreversible character, was produced in this patient, simulating exactly the findings that Brindley has reported in total hepatectomy of dogs Laboratory tests of this patient's blood showed complete prolongation of prothrombin time, citrate poisoning with severe calcium depletion, and irreversible heparinization We agree, therefore, with the article presented in a recent issue of the *Journal of the American Medical Association* on citrate poisoning as a major hazard of hypothermia with associated decrease in circulation to the liver Any transfusions used in such physiologic preparations should be prepared by means of a resin membrane to remove the calcium from the blood so as not to subject the patient to quantities of citrate or heparin which the liver cannot detoxify

BLOOD VOLUME STUDIES IN THORACIC SURGICAL PATIENTS USING RADIOACTIVE IODINATED HUMAN SERUM ALBUMIN (RIHSA)

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THE importance of a normal preoperative blood volume with adequate replacement of blood lost during and after major operative procedures is recognized by all surgeons. The surgeon often relies on his clinical acumen and a routine blood count and hematocrit as to the blood requirements of the patient before, during and after major surgery. The use of these methods of appraisal has resulted in serious untoward consequences for some patients due to the administration of too little or too much blood.

There are a number of substances, isotopic and otherwise, as well as techniques by which the blood volume, plasma volume and red cell volume may be determined. The early studies of blood loss during surgery involved the use of colorimetric (acid hematin)[1] or gravimetric (weighed sponge)[2, 3] methods. These techniques are useful and their practical value is recognized, but numerous studies have shown that they do not possess a high degree of accuracy. When compared with simultaneous estimations of the blood volume utilizing more precise methods, it has been shown that there is a postoperative reduction in the blood volume of from 30 to 50 per cent more than one would anticipate on the basis of the blood loss estimated gravimetrically or colorimetrically.[4-6] In addition to the blood loss during the surgical procedure, it has been established that there is continued loss of red blood cells in the postoperative period; at times the postoperative blood loss may equal or even exceed that lost during the operation.[4]

Previous investigators of this problem have used a dye dilution method employing Evans blue dye (T-1824), P labeled erythrocytes or radioactive iodinated human serum albumin (RIHSA) in their studies. Although we have used RIHSA most often, we have also determined the blood volume using P and Cr tagged erythrocytes. In a number of patients we have employed Cr and RIHSA simultaneously, the former for the red cell volume and the latter for the plasma volume, the sum of these values being the blood volume. As one would expect, the values for each of the above volumes depend upon whether one compartment (plasma or cells) is determined directly and the other one indirectly from it and the hematocrit, or whether both compartments are determined independently.

TABLE I SEGMENTAL RESECTION

PATIENT	DIAGNOSIS	SITE	IMMEDIATE PREOPERATIVE VALUES				GIVEN AT OPERATION	IMMEDIATE POSTOPERATIVE VALUES				ONE WEEK POSTOPERATIVE VALUES			
			BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)	BLOOD (C C)	BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)	BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)
D F	Tbc	LLL	5368	2947	2421	45 1	1500	3932	2556	1376	35 0	4425	3022	1403	31 7
A D	Tbc	RUL	5652	2730	2922	51 7	1000	4838	2298	2540	52 5	4508	2655	1853	41 1
L D	Tbc	LUL	5377	2984	2393	44 5	1000	5047	2978	2069	41 0	5254	3184	2070	39 4
R C	Tbc	RUL	6672	3503	3169	47 5	1000	4683	2557	2126	45 4	5721	3381	2340	40 9
N B	Tbc	RUL	4599	2437	2162	47 0	1000	4066	2285	1781	43 8	4423	2729	1694	38 3
H E	Tbc	RUL	3257	1668	1589	48 8	1500	3521	2049	1472	41 8	3980	2304	1676	42 1
C R	Tbc	LUL	5221	2877	2344	44 9	1500	4048	2259	1789	44 3	4292	2983	1309	30 5
W L	Tbc	LLL	4908	2748	2160	44 0	1500	3934	2274	1660	42 2	4373	2694	1679	38 4
C K	Tbc	RUL	5230	2563	2667	51 0	1000	4498	2339	2159	48 0	4814	2772	2042	42 4
E R	Tbc	RUL	5871	2965	2906	49 5	1500	4834	2550	2288	47 3	5465	3219	2246	41 1
I C	Tbc	RUL	5297	3099	2198	41 5	2000	4956	2954	2002	40 4	4434	2589	1845	41 6
R S	Tbc	RUL	7408	3904	3504	47 3	1000	6406	3370	3036	47 4	6918	3736	3182	46 0
P B	Tbc	RUL	5180	3056	2124	41 0	2000	4307	2662	1645	38 2	4594	3096	1498	32 6
D M	Tuberculoma	RUL	6821	3438	3383	49 6	1000	6422	3153	3269	50 9	5307	3067	2240	42 2
D S	Tbc	LUL	5331	3044	2287	42 9	2500	4546	2609	1937	42 6	5114	3247	1867	36 5
I M	Tbc	LUL	4871	2635	2236	45 9	1000	4365	2457	1908	43 7	3506	1963	1543	44 0
W F	Fibrocaseous granuloma	RUL	5737	3127	2610	45 5	1000	5127	2666	2461	48 0	5667	3338	2329	41 1
I H	Tbc	LUL	5545	2983	2562	46 2	2000	4251	2550	1701	40 4	4883	4130	1743	35 7
M B	Bronchiectasis	LUL	3588	2121	1467	40 9	1500	3185	1844	1341	42 1	3465	2020	1445	41 7
W J	Tbc	RUI	5101	2530	2571	50 4	1500	4734	2239	2495	52 7	4976	2727	2249	45 2
V S	Tbc	RUL	6163	3310	2853	46 3	1500	5683	3200	2483	43 7	6348	4190	2158	34 0
P Y	Tbc	RUL	5917	2994	2923	49 4	1500	5562	2653	2909	52 3	5886	3178	2708	46 0
W T	Tbc	RUL	5910	3162	2748	46 5	2000	4756	2673	2083	43 8	5569	3464	2105	37 8
J K	Tbc	RUL	5641	2804	2837	50 3	1000	4948	2583	2365	47 8	6137	3688	2449	39 9
C C	Tbc	RUL	5643	2889	2754	48 8	500	5224	2775	2449	46 8	5913	3441	2472	41 8
R F	Tbc	RUL	5914	3198	2746	16 2	1000	4852	2746	2106	43 4	6040	3630	2410	39 9
H G	Fibrocaseous granuloma	RUL	5526	2669	2857	51 7	1100	6312	3206	3106	49 2	6378	3246	3132	49 1
K H	Tbc	RUL	5869	3375	2494	42 5	1000	5806	3350	2456	42 3	5879	3886	1993	33 9
I H	Fibrocaseous granuloma	LUL	4958	2628	2330	47 0	1000	5377	2855	2522	46 9	5785	3083	2702	46 7
C I	Tbc	RUL	4862	2801	2061	42 4	500	4884	2774	2110	43 2	5576	3212	2304	42 4
I K	Tbc	RUL	6189	3435	2754	44 5	1000	6254	3308	2946	47 1	7131	4143	2988	41 9
I C	Tbc	LUL	6082	3100	2682	44 1	1500	5396	3184	2212	41 0	6532	4050	2482	38 0

P. F.	[illegible]	I I L	1162	[illegible]	[illegible]09	19.[illegible]	1000	1507	2710	1707	30.2	1110	2717	1720	18.9
[illegible]	[illegible]	I I I	7802	1191	2611	15.0	1000	1931	2787	2140	13.5	5887	1015	2272	18.6
[illegible]	[illegible]	I I I	917	1160	2837	17.3	1000	5876	3071	2782	17.5	6071	1521	2550	12.0
J. H.	[illegible]	L I I	[illegible]	[illegible]	2810	17.0	1000	5520	3081	2112	11.2	5178	1008	2170	11.9
J. J.	[illegible]	P I I	10[illegible]8	2110	17[illegible]8	12.8	1500	1513	1978	1535	11.7	3998	2517	1151	30.1
[illegible]	[illegible]	I I I	6115	3036	3109	50.6	1000	5101	2086	2718	50.3	5010	1209	2101	12.8
[illegible]	[illegible]	R I I	3167	1919	1218	39.1	2000	1301	1986	1318	39.0	3080	2121	1305	37.0
[illegible]	[illegible]	I I I	1117	2357	2090	17.0	1000	1130	2171	2083	10.5	1711	2720	2007	12.1
[illegible]	[illegible]	P I I	5158	2701	2155	17.6	1000	1057	2501	2090	15.0	5251	1215	2000	18.2
[illegible]	[illegible]	I I I	1801	2167	1611	11.0	1000	1000	2118	1518	11.1	1920	1101	1111	20.1
H. K.	[illegible]	I I I	1037	1919	1088	10.1	950	1077	2228	1119	39.1	1021	2515	1100	15.9
J. C.	[illegible]	L I I	[illegible]527	2795	2728	19.1	1000	5118	2061	2071	50.1	5021	1232	2180	12.5
Mean			[illegible]110	2812	2171	10.1	1251	1808	2012	2100	11.7	5100	1110	2077	19.8

The purpose of this report is to describe the blood volume changes in a group of 65 patients who underwent excisional pulmonary surgery. Radioactive iodinated human serum albumin was used in all of these studies. The operations performed consisted of 44 segmental resections, 8 lobectomies, 8 wedge resections, and 5 local enucleations. Three blood volume determinations were done in each case. These studies were carried out one or two days preoperatively, immediately after operation, and 7 days postoperatively.

MATERIALS AND METHODS

The radioactive iodinated human serum albumin (RIHSA) was obtained from Abbott Laboratories, Chicago, Illinois. Using 0.85 per cent salt solution as the diluent, a 5 per cent solution of normal human serum albumin was made which contained 2 microcuries of RIHSA per cubic centimeter. From a calibrated syringe, between 10 and 20 c.c. of the above solution were injected into a vein. Approximately 20 microcuries of RIHSA were used for each determination. After an interval of 10 minutes, 10 c.c. of blood was withdrawn without stasis from an antecubital vein in the opposite arm. Potassium and ammonium oxalates were used as the anticoagulant. Prior to each subsequent blood volume determination, a specimen of blood was obtained to correct for residual activity from the preceding study.

Hematocrits were obtained in duplicate, using Wintrobe hematocrit tubes, and the average value was used in the computations. Three cubic centimeter aliquots of whole blood were pipetted into small glass vials and inserted into a well-type scintillation counter. The crystal used was 35 per cent efficient for I^{131} gamma rays and was not volume sensitive between 1 and 4 c.c. Two aliquots were obtained from each blood specimen and each aliquot was counted twice. For the control, a 1:500 dilution of the injection solution was used. Duplicate 3 c.c. aliquots were counted twice with each blood volume determination. The counting error for the whole blood specimen and control was 3 per cent or less.

Calculation of the blood volume, plasma volume, and red-cell volume was performed as follows:

$$\text{Blood volume} = \frac{\text{Net counts/minute/c.c. control} \times 500 \times \text{c.c. injected}}{\text{Net counts/minute/c.c. whole blood}}$$

$$\text{Plasma volume} = \text{Blood volume} \times \text{plasmacrit}$$

$$\text{Red-cell volume} = \text{Blood volume} \times \text{hematocrit}$$

The amount of blood lost during the operation was taken to be the difference between the preoperative and immediate postoperative blood volumes plus the amount of blood given at surgery. The seventh postoperative day blood volume minus the immediate postoperative value represents the blood lost or gained during the first postoperative week. The seventh postoperative day blood volume less the preoperative blood volume is the blood excess or deficit, relative to the preoperative value, at the end of the first postoperative week. Changes in the plasma and red-cell volumes were calculated similarly. In no instance was a blood volume determination performed while the patient was receiving blood. No patient received blood or plasma between the first and third blood volume determinations except at surgery. All estimated blood losses during surgery were obtained by the dry weighed sponge technique plus suction bottle contents. It was assumed that each 500 c.c. of whole blood transfused contained 200 c.c. of red cells and 300 c.c. of plasma. Tables I through VIII list the patients, their diagnoses, the operations performed, and the observed blood volume changes.

RESULTS

TABLE II. SEGMENTAL RESECTION

	ESTIMATED LOSS AT OPERATION	GIVEN AT OPERATION	ACTUAL LOSS AT OPERATION			GAIN OR LOSS—FIRST POSTOPERATIVE WEEK			EXCESS OR DEFICIT—ONE WEEK POSTOPERATIVE VS. PREOPERATIVE		
PATIENT	BLOOD (C.C.)	BLOOD (C.C.)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)
D. E.	850	1500	2936	1291	1645	+493	+466	+27	-943	-75	-1018
A. P.	900	1030	1814	1032	782	-330	+327	-657	-1144	-75	-1069
L. D.	800	1000	1330	606	724	+207	+206	+1	-123	+200	-323
E. C.	500	1000	2989	1546	1443	+1038	+824	+214	-951	-122	-829
N. B.	800	1000	1533	752	781	+357	+444	-87	-176	+292	-468
H. E.	1000	1500	1236	519	717	+459	+255	+204	+723	+636	+87
C. J.	1200	1500	2673	1518	1155	+244	+724	-480	-929	+106	-1035
W. L.	1200	1500	2474	1374	1100	+439	+420	+19	-535	-54	-481
C. K.	700	1000	1732	824	908	+316	+433	-117	-416	+209	-625
E. I.	1000	1500	2533	1315	1218	+627	+669	-42	-406	+254	-660
T. C.	1200	2000	2341	1345	996	-522	-365	-157	-863	-510	-353
J. S.	800	1000	2042	1174	868	-512	-366	-146	-490	-168	-322
J. R.	1400	2000	2873	1594	1279	+287	+434	-147	-586	+40	-626
D. M.	800	1000	1799	885	914	-1115	-86	-1029	-1514	-371	-1143

TABLE III LOBECTOMY

PATIENT	DIAGNOSIS	SITE	IMMEDIATE PREOPERATIVE VALUES				GIVEN AT OPERATION	IMMEDIATE POSTOPERATIVE VALUES				ONE WEEK POSTOPERATIVE VALUES			
			BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)	BLOOD (C C)	BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)	BLOOD (C C)	PLASMA (C C)	CELLS (C C)	HEMATOCRIT (%)
E H	Tbc	RUL	6079	3362	2717	44.7	1510	5187	2900	2287	44.1	6084	3882	2202	36.2
H E	Tbc	LLL	5399	2915	2484	46.0	500	5154	2871	2283	44.3	4874	3183	1691	34.7
D G	Tbc	LLL	5481	2949	2532	46.2	1000	5842	3009	2833	48.5	5405	3102	2303	42.6
H W	Fibrocaseous granuloma	RLL	4392	2257	2135	51.4	1500	3984	2016	1968	49.4	4351	2332	2019	46.4
J C	Tbc	RUL	5800	2964	2836	48.9	1500	5827	3135	2692	46.2	5651	3351	2300	40.7
P D	Tbc	RLL	3066	2140	926	30.2	1500	3226	2032	1194	37.0	3719	2503	1216	32.7
J P	Tbc	RUL	5367	2823	2544	47.4	2500	4139	2268	1871	45.2	4870	3326	1544	31.7
J S	Bronchiectasis	RML RLL	5975	3322	2653	44.4	2000	5241	2904	2337	44.6	5734	3440	2294	40.0
Average			5195	2842	2353	44.9	1500	4825	2642	2183	44.9	5086	3140	1946	38.1

TABLE IV. LOCAL EXCISION

		IMMEDIATE PREOPERATIVE VALUES				EST. AT OPERATION	IMMEDIATE POSTOPERATIVE VALUES				ONE WEEK POSTOPERATIVE VALUES			
		BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)	BLOOD (C.C.)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]00	[illegible]70	[illegible]	2857	47.7	[illegible]	[illegible]	2712	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]127	47.2	500	[illegible]870	2017	221[illegible]	[illegible]	5080	2800	2100	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1000	1211	2151	1803	[illegible]	5002	[illegible]	2110	47.0
[illegible]	[illegible]	[illegible]	[illegible]	2316	[illegible]	500	1121	2061	1760	[illegible]	[illegible]182	1240	1933	47.1
[illegible]	[illegible]	[illegible]	[illegible]	1005	[illegible]	500	[illegible]	[illegible]	2858	45.1	5820	[illegible]	2111	42.0
[illegible]		[illegible]	[illegible]	2[illegible]	[illegible]	[illegible]000	5080	2800	2280	[illegible]	[illegible]002	[illegible]	2202	[illegible]

TABLE V WEDGE RESECTION

PATIENT	DIAGNOSIS	SITE	IMMEDIATE PREOPERATIVE VALUES				GIVEN AT OPERATION	IMMEDIATE POSTOPERATIVE VALUES				ONE WEEK POSTOPERATIVE VALUES			
			BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)	BLOOD (C.C.)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)	BLOOD (C.C.)	PLASMA (C.C.)	CELLS (C.C.)	HEMATOCRIT (%)
R. A.	Tbc	LUL LLL	6355	3279	3076	48.4	2000	5469	3123	2346	42.9	6910	4429	2481	35.9
C. F.	Tbc	RUL	4709	2552	2157	45.8	1000	5244	2842	2402	45.8	4727	2685	2042	43.2
V. M.	Tbc	LUL	5352	2879	2473	46.2	500	4990	2695	2295	46.0	5646	3348	2298	40.7
S. S.	Tbc	LUL	6023	3162	2861	47.5	1000	6335	3446	2889	45.6	6317	3740	2577	40.8
A. M.	Tbc	RUL	5715	3155	2560	44.8	1000	6058	3750	2308	38.1	6355	3978	2377	37.4
G. P.	Congenital cystic disease	LLL	4678	2503	2175	46.5	1000	4337	2459	1878	43.3	5023	3074	1949	38.8
I. V.	Tbc	LUL	4378	2141	2237	51.1	500	4578	2391	2187	47.8	5007	2704	2303	46.0
I. H.	Tbc	RUL	5394	2864	2530	46.9	500	5261	2883	2378	45.2	6231	3963	2268	36.4
Average			5326	2817	2509	47.1	937	5284	2949	2335	44.3	5777	3490	2287	39.9

The Tables which follow, IX through XII, summarize the blood losses during various pulmonary resections, the estimated losses, blood replacement, the additional blood lost in the first postoperative week and present a comparison of the status of the blood volumes preoperatively and one week postoperatively.

TABLE IX. BLOOD LOSS DURING VARIOUS PULMONARY RESECTIONS

OPERATION	NO. OF PATIENTS	MAXIMUM (C.C.)	MINIMUM (C.C.)	AVERAGE (C.C.)	PLASMA (C.C.)	CELLS (C.C.)
Segmental resection	44	3294	314	1759	950	809
Lobectomy	8	3728	639	1870	1100	770
Local enucleation	5	2250	572	1148	632	516
Wedge resection	8	2886	300	979	430	549

These figures indicate that the average blood loss during excisional pulmonary surgery is large and in certain patients it may be extremely so, amounting in some cases in this series to over 70 per cent of the patient's total blood volume. The greatest individual blood losses as well as the highest average losses occurred in patients in whom anatomical resection of a lobe or a segment was performed, while smaller losses were encountered in patients treated by localized excisions. The losses in plasma and red-blood cells were generally in the normal proportions. The large average losses in these thoracic surgical patients are comparable for similar operations to those reported by Forsee,[4] Baronofsky,[3] Thomas,[7] Berlin,[9, 10] Miller,[11] and their associates, and by White and Buxton.[8]

TABLE X. AVERAGE ESTIMATED BLOOD LOSS, BLOOD REPLACEMENT, ACTUAL LOSS, AND P.O. DEFICITS

		SEGMENTAL RESECTION (C.C.)	LOBECTOMY (C.C.)	LOCAL ENUCLEATION (C.C.)	WEDGE RESECTION (C.C.)
Gravimetrically estimated loss		891	1214	416	736
Average given by tranfusion		1251	1500	600	937
Actual loss		1759	1870	1148	979
Postoperative deficits	Blood	-508	-370	-548	-42
	Plasma	-200	-200	-272	+132
	RBC	-308	-170	-276	-174

The figures in Table X demonstrate the deficiencies of the gravimetric method of determining blood loss during surgery. Although the amount given by transfusion exceeded the estimated loss in every case, averaging between 25 and 30 per cent more, there was a significant average postoperative deficit in each group of patients. In the segmental resection group, only 71 per cent of the blood lost during surgery was replaced and over 60 per cent of the deficit was due to red cells. Eighty per cent of the operative blood loss was replaced in the lobectomy patients; the 5 local enucleation patients received only 52 per cent replacement, while the 8 patients who underwent wedge resections showed a postoperative deficit of only 42 c.c. and the postoperative blood volume was 99 per cent of the preoperative value. The deficiency in red-blood cells predominated in all patient groups. This was particularly striking in the patients who had wedge resections. These patients showed an average immediate postoperative plasma volume 132 c.c. greater than the pre operative value but their red cells decreased an average of 174 c.c., the loss in erythrocytes accounting for 100 per cent of the 42 c.c. diminution in total blood volume. These observations agree with those of Stanton,[6] Loree[4] and others who have found that blood replacement on the basis of gravimetric estimations of loss results in undertransfusion to the extent of about 40 per cent. *The fact that the postoperative deficit in erythrocytes generally exceeds that of plasma is interesting and important.*

TABLE XI. AVERAGE BLOOD VOLUME CHANGES IN THE FIRST POSTOPERATIVE WEEK

	SEGMENTAL RESECTION (C.C.)	LOBECTOMY (C.C.)	LOCAL ENUCLEATION (C.C.)	WEDGE RESECTION (C.C.)
Blood volume gain first P.O. week	388	261	582	493
Plasma volume gain first P.O. week	477	498	570	542
RBC loss or gain first P.O. week	-89	-237	12	-49

Table XI reflects the changes in the average blood volume in the various groups of patients in the week following operation. Thirty-eight of the 44 segmental resection patients showed an increase in blood volume during the first postoperative week and this increase averaged 388 c.c. The plasma volume increased in 39 patients and the average plasma volume gain in the entire group was 477 c.c. Nineteen of these patients showed an increase in the red-cell volume during this period but there was a decrease in 25 patients. Those with an increase had an average gain of 112 c.c., while 25 patients exhibited an average loss of 242 c.c. The average loss in the whole group was 89 c.c. per patient. The 8 lobectomy patients showed an average blood volume gain of 261 c.c. during the first postoperative week. There was an increase in 5 patients and a decrease in 3. The entire gain in blood volume was due to an

TABLE XII AVERAGE DIFFERENCES BETWEEN THE PREOPERATIVE BLOOD VOLUME AND THE BLOOD VOLUME AT THE END OF THE FIRST POSTOPERATIVE WEEK

	SEGMENTAL RESECTION (C C)	LOBECTOMY (C C)	LOCAL ENUCLEATION (C C)	WEDGE RESECTION (C C)
Blood Vol , first P O week vs Preop	-120	-109	34	452
Plasma Vol , first P O week vs Preop	277	298	298	673
RBC Vol , first P O week vs Preop	-397	-407	-264	-221

into plasma and red cells, the situation does not appear so favorable Those patients who had a segmental resection had an average plasma volume which exceeded their preoperative figure by 277 c c, but they showed an average red-cell decrease of 397 c c Thirty-five patients had a plasma volume at the end of one week which was greater than that preoperatively and only 9 had volumes which were less In contrast, 39 of 44 patients had red-cell volumes at the end of the first postoperative week which were less than their preoperative volumes, while an increase occurred in only 5 The average red-cell volume one week postoperatively was 2,077 c c in comparison with the preoperative volume of 2,474 c c Since the immediate postoperative deficit was 308 c c, it is apparent that the majority (78 per cent) of this 397 c c deficit was due to inadequate replacement of blood at the time of operation Essentially the same changes occurred in the lobectomy patients Although the plasma volume at the end of the first postoperative week exceeded the preoperative value by 298 c c, the red-cell volume was 407 c c less One hundred seventy cubic centimeters (42 per cent) of this deficiency was due to underreplacement at the time of surgery, while an additional 237 c c of red cells were lost during the first postoperative week The red-cell losses in the local enucleation and wedge resection patients were not as great as in the patients with more extensive operations, but they were substantial The 34 c c increase in average blood volume in the local enucleation patients during the first postoperative week, as compared with their preoperative value, was accomplished by an average plasma volume increase of 298 c c while the red-cell volume was decreased 264 c c Since these patients showed an immediate postoperative deficit of an average of 276 c c of red cells, this deficiency could be completely accounted for, on the average, by underreplacement of blood during surgery The red-cell volume of the 8 patients who had wedge resections averaged 221 c c less at the end of the first postoperative week than preoperatively but the plasma volume had increased 673 c c during the same interval, accounting for an increased blood volume of 452 c c In view of the fact that the average immediate postoperative red-cell deficit in these patients was 174 c c, 78 per cent of the decrease at the end of the first postoperative week was due to too little blood at the time of surgery The significance of these deficits in red cells at the end of the first postoperative week becomes apparent when it is appreciated that the persisting deficit in the most favorable group of patients (local enucleations) amounted to the quantity of red cells normally contained in slightly over a pint of whole blood (about 10 per cent of the normal blood volume), while the least favorable group (lobectomies) showed a diminution equivalent to the red cells in two pints of whole blood or about 20 per cent of the normal blood volume

SUMMARY

1. The blood volume changes in 65 patients who underwent pulmonary resections are presented.

2. The blood loss during intrathoracic operations is large and replacement on the basis of gravimetric estimations of loss results in significant undertransfusion. The deficit averages about 40 per cent of the total blood loss.

3. Restoration of the total blood volume toward normal during the first postoperative week is accomplished by an increase in the plasma fraction. There is a continued loss of red cells during this period.

4. In most patients the red cell deficit at the end of the first postoperative week is due largely to inadequate replacement of blood lost during surgery.

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INDUCED CARDIAC ARREST FOR INTRACARDIAC SURGICAL PROCEDURES

An Experimental Study

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Alfredo Lepore, M.D. (by invitation)
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THE ability of the heart to survive circulatory interruption might be increased by removing the necessity for it to continue beating in the face of a diminished blood supply. When the venae cavae are occluded, the coronary blood flow is abruptly curtailed while ventricular systolic contractions persist. When this situation is prolonged, as in open heart operations with the aid of hypothermia, the discrepancy between blood supply and muscular activity may be accentuated. With this in mind, a series of experiments were done to determine if the heart could be deliberately stopped while its blood supply was obstructed and then restarted again, and if recovery was thereby aided.

We were familiar with the unsuccessful attempts of Bjork[1] at inducing reversible cardiac arrest by local freezing of the heart and by injections of acetylcholine. Niazi and Lewis[2] demonstrated the ability of the rat heart to survive prolonged periods of cardiac arrest which occurred at temperatures in the vicinity of 5.0° C. Senning[3] and Glenn and Sewell[4] induced ventricular fibrillation in dogs while perfusing the body with an extracorporeal circuit. They demonstrated that prolonged periods of fibrillation were tolerated under these conditions with survival, and emphasized the advantage of the nonbeating heart in avoiding entrance of air into the coronary arteries.

A method was developed of suddenly stopping the normal heartbeat which was consistent and reversible. This consists of rapidly perfusing the coronary system with a 5 per cent solution of potassium chloride. With the ascending aorta compressed, 1 c.c. per kilogram of body weight is injected into the cavity of the left ventricle. Manually squeezing the ventricles aids entrance of the solution into the coronaries. Usually ventricular activity ceases in about 30 seconds. The still heart may then be manipulated or incised. Following completion of the surgical procedure the heart may be started again by simple massage. As the coronary circulation is manually restored, the potassium chloride is washed out and diluted in the blood stream. The heart which is flaccid at first regains its tone and then usually goes through a phase of coarse fibrillation

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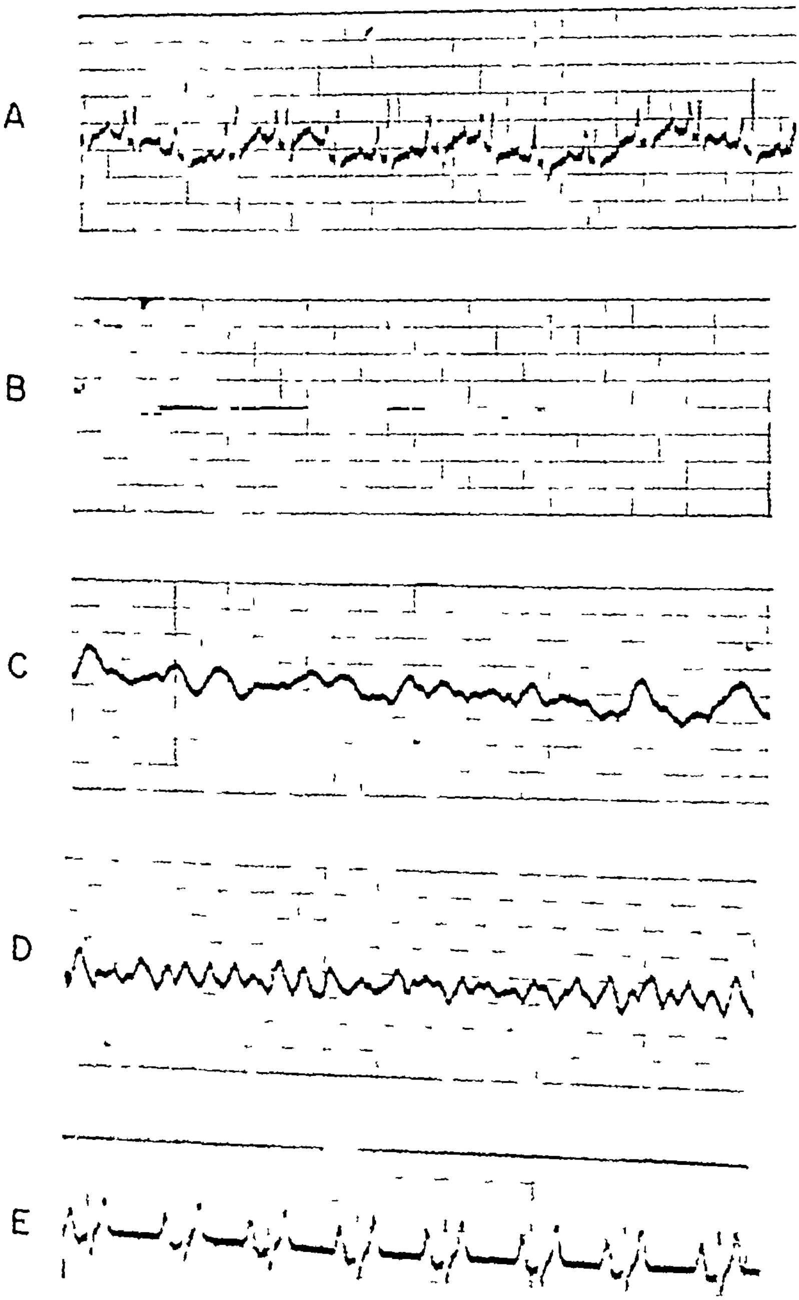
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(Fig 1) Countershock readily converts this to a regular rhythm Calcium is not necessary to neutralize the potassium chloride for resuscitation purposes In fact, it proves troublesome by making the fibrillation phase difficult to control

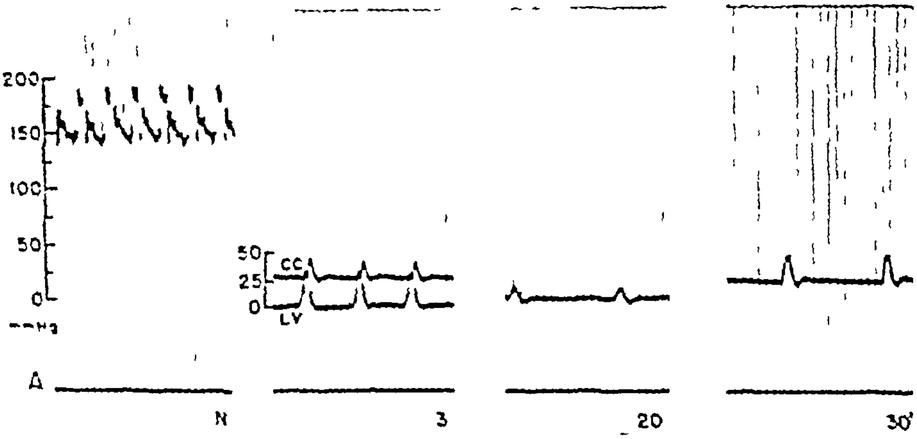
A series of acute experiments were done to compare the recovery of hearts stopped during vena caval occlusion with that of hearts allowed to beat during the occlusion period The venae cavae were occluded for periods of 10 and 12 minutes in 20 dogs In one-half of the animals, the heart was stopped during the occlusion In each case, the chest was opened in the right fourth interspace under endotracheal ether-oxygen anesthesia The azygos vein was ligated and the venae cavae occluded with snares In most animals an incision was made in the right atrium After closure of the atrial incision and release of the caval snares, resuscitative measures were begun and continued for as long as 20 minutes, if necessary These consisted of cardiac massage, countershock, and, in some animals, intraventricular epinephrine, 0 25 c c of a 1 1,000 solution At 30 minutes, following release of the caval snares, the status of the heart was evaluated by direct inspection and by recordings of the ventricular and arterial pressures

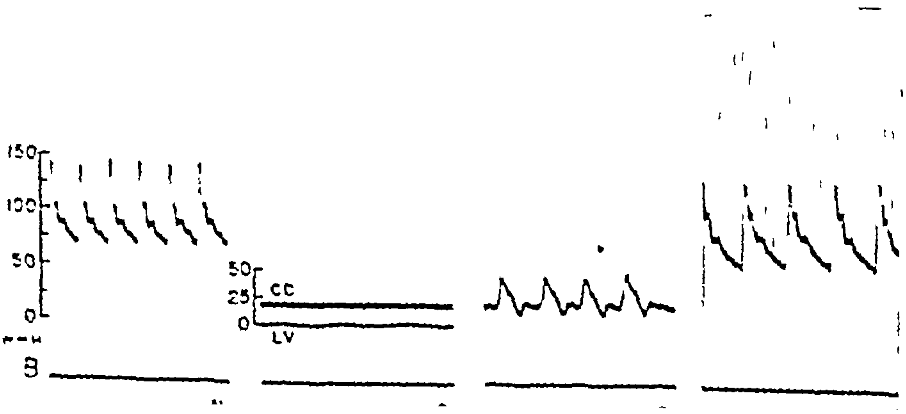
Of the hearts allowed to beat during the occlusion, 9 of 10 had ventricular fibrillation when the caval snares were released Regular rhythm was restored with countershock in all but one heart After restoration of regular rhythm, injection of epinephrine was needed in every case because of hypotension This produced a rise in blood pressure which was only temporary The average systolic blood pressure, 30 minutes after release of the caval snares, was 72 mm Hg The average time of onset of regular beats was 8 minutes

Of the 10 arrested hearts, 9 were restored to regular rhythm The average time of onset of coordinated beats following release of the caval snares was 8 5 minutes Epinephrine was needed in one-half of the cases Its effect was quite different from that in the other group, however, in that the blood pressure increase was sustained The average systolic blood pressure at 30 minutes was 135 mm Hg (Fig 2)

These experiments seemed to indicate that the stopped heart had a slightly better tolerance of circulatory occlusion Because of the brain damage occurring with lengthy interruption of the circulation at normal temperatures, of course, no long-term observations were possible Therefore, survival experiments were done using hypothermia to protect the brain

Dogs under ether-oxygen anesthesia were cooled in ice water At rectal temperatures of 26° C, the heart was stopped for from 10 to 20 minutes in a series of dogs in which atrial and ventricular septal defects were produced and repaired Large defects were cut out of the interatrial septum and were closed with pedicled flaps of the right atrial wall which were in turn replaced with pedicled pericardial flaps Ventricular septal defects were made through incisions in the right ventricular wall and closed by approximation of the edges of the defect with silk sutures The performance of these operations on a completely quiet and bloodless heart was relatively simple No difficulty was encountered with air embolism of the coronary arteries Of 14 dogs in which technically satisfactory procedures were carried out, 12 survived operation and rewarming (40° C warm water bath). Nine were completely well for a week or more and 6 continue well about four months or more postoperatively. One half of these represent ventricular and half atrial septal defect repairs.





In order to compare these results with those from other techniques, a control series of 30 dogs was subjected to circulatory occlusion at 22° C for 30 minutes. In 10 dogs the venae cavae were occluded. In 10, both the venae cavae and the aorta and pulmonary artery were occluded. In the other 10, the venae cavae were occluded and the right ventricle then stimulated with an inductorium current to induce ventricular fibrillation. The results of these experiments are compared in Table I.

TABLE I. CIRCULATORY OCCLUSION 30 MINUTES AT 22° C

	NUMBER OF DOGS	INTRACTABLE FIBRILLATION	REWARMING DEATH	POSTOPERATIVE DEATH	SURVIVORS	PER CENT
Induced cardiac arrest	20	1	2	2 (1 and 6 days)	15	75
Induced fibrillation	10	1	0	3 (36 hours)	6	60
Caval occlusion	10	0	1	2 (24 hours)	7	70
Caval and outflow occlusion	10	0	1	3 (1 and 7 days)	6	60

The survival rates were similar no matter what technique was used. Four dogs with caval occlusion and 6 with caval and outflow occlusion developed ventricular fibrillation. All of these animals were defibrillated, although some required multiple countershocks. In the latter category, 2 in each group died during the first twenty-four hours postoperatively with histologic evidence of thermal damage to the heart. One dog in each group died during rewarming. Of the animals in which ventricular fibrillation was induced, only 1 had intractable fibrillation when the countershock was used at the end of the 30 minute period. Three animals in this group died during the first 36 hours postoperatively, all of which had multiple countershocks.

DISCUSSION

It is astonishing at first to see the ease with which the heart can be stopped and then started again after prolonged arrest. The technique of potassium chloride injection is a modification of the early defibrillation method developed by Hooker[5] and Wiggers.[6] Restoration of the normal beat seemed to be no more difficult in those animals which had ventricular incisions, although no controlled studies were done to determine the soundness of this impression. The similarity in the results of the control experiments for circulatory occlusion of 30 minutes at 22° C was somewhat surprising, particularly in the group with induced fibrillation.

SUMMARY

The deliberate production of cardiac arrest for the purpose of opening the heart surgically was found to be possible with recovery. The heart was stopped with the injection of potassium chloride into the left ventricle. Resumption of the normal heartbeat was obtained by massage of the heart and electrical countershock. With the aid of hypothermia, cardiac arrest for periods of 10 to 20 minutes was induced and intracardiac operations carried out with recovery of the animals. Controlled experiments of circulatory occlusion for 30 minutes at 22° C. demonstrated virtually no difference in survival rates when the heart was allowed to beat, stopped, or even made to fibrillate during the entire period of occlusion.

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DISCUSSION

DR. RALPH ADAMS, Boston, Mass.—Approximately ten people have inquired of me regarding the fate of a 10-year-old child whom I mentioned before this Association a year ago. At that time he was alive four days after surviving one hour and fifty minutes of ventricular fibrillation and currently then had lower nephron nephrosis.

I am pleased to report that the child apparently is now normal in all respects and does schoolwork and other activity as a healthy boy should.

Subsequently, a patient with coarctation of the thoracic aorta had ventricular fibrillation for [illegible] minutes and has recovered and is all right. He did not have any renal symptoms, which has made me wonder if there was some kidney protection afforded by the chronic decreased circulation below the coarctation.

OPEN LEFT HEART SURGERY IN DOGS DURING HYPOTHERMIC ASYSTOLE WITH AND WITHOUT EXTRACORPOREAL CIRCULATION

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(BY INVITATION), JAMES T GRACE, M D (BY INVITATION), AND
RAYMOND M JONES (BY INVITATION)
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ALTHOUGH the body temperature of dogs can be rapidly lowered to the terminal degree of about 16° C [1] and the animals successfully resuscitated by immersion in warm water,[2] this extreme condition cannot be fully utilized for open intracardiac surgery[3] since the high mortality due to anoxia and ventricular fibrillation prohibits any human application Therefore, the most satisfactory clinical results have been achieved at about 25° C with a safe cessation of circulation of about 5 to 8 minutes [4, 5]

Attempts have been made to lower the terminal temperature of dogs by substituting a pump oxygenator for the function of the failing heart[6, 7] and although 1 dog survived a body temperature of 12° C, all other animals died in shock of unknown origin By circulating, oxygenating, and refrigerating venous blood in a gas dispersion pump-oxygenator,[8] it has been possible to achieve survival of dogs after cardiac arrest of one hour's duration during hypothermia of 0° C [9] Thus, the use of such biomechanical equipment as a research tool for physiologic investigations has produced a condition which does not have to be fully utilized for the short-term applications of open intracardiac surgery

In about 40 minutes of blood cooling, the temperature inside the right heart is lowered to about 5° C, and in 15 minutes of bloodwarming, it is raised to 27° C The differential hypothermia[10] between the upper and the lower part of the body reaches 20° C As the temperature inside the heart reaches about 13° C, the last contraction is recorded and the heart remains in hypothermic asystole as long as this low temperature is maintained On rewarming, the heart starts to beat in normal rhythm and at about 28° C the pump oxygenator can be turned off Such a procedure lends itself in a most advantageous way to prolonged intracardiac surgery under direct vision[11] since greater technical accuracy is attainable if the motions of the lungs and of the heart are arrested By the cannulation of peripheral blood vessels only, the surgical procedure is shortened and trauma to the great vessels in the chest is avoided At no time during the experiment does the nervous system, the heart, or the viscera suffer from anoxia or from carbon dioxide retention and therefore no time limit is set

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Read at the Thirty-fifth Annual Meeting of The American Association for Thoracic Surgery at Atlantic City N J April 24 to 26 1955 for the careful exploration and repair of intracardiac lesions. Because of the low oxygen consumption of the cold and inactive myocardium the coronary flow can be drastically reduced, resulting in a bloodless operating field. Special precautions against air embolism are not required since the heart in arrest ejects neither blood nor air into the aorta. In a series of 13 consecutive experiments with left cardiotomies 9 animals survived the procedure without any clinically detectable ill effect and were sacrificed after an observation period of one month. Four dogs died of postoperative complications such as infection, thrombosis, and hemothorax.

These studies led to the conclusion that large nonhibernating mammals can survive the lowering of their body temperature to or close to the freezing point of water just like the small nonhibernating rat[17] if the function of the heart is substituted by a mechanical device. Furthermore, the absence of ventricular fibrillation was surprising and could have been due to the relief of the work load of the heart by the pump-oxygenator or by the pretreatment with quinidine.[1, 11] The effect of carbon dioxide on cardiac rhythm[1] and the prevention of ventricular fibrillation in dogs during profound hypothermia of 7° to 12° C. by the addition of carbon dioxide to the inspired air[1] indicate that the exclusion of the heart by a pump-oxygenator is not necessary for the production of hypothermic asystole. We assumed, therefore, that the pretreatment with quinidine must have been the only important factor in the production of hypothermic cardiac arrest without ventricular fibrillation.

Seventy-six dogs were anesthetized with Nembutal and given 30 to 40 mg. of quinidine per kilogram of weight in 200 c.c. saline solution by slow intravenous drip before being immersed in ice water. Shivering was controlled with small amounts of Pentothal sodium, and when the respiration started to become depressed, hyperventilation with oxygen was started. At body temperatures of 18° to 13° C., as measured in the thoracic esophagus, cardiac standstill or very infrequent beats were recorded and in no instance did ventricular fibrillation develop. Nevertheless, only 8 to 10 per cent of these animals were long-term survivors. Even in cases with very short interruption of the circulation and successful re-establishment of cardiac function during rewarming, the animals succumbed in delayed shock the next day.

The following attempts were made to overcome this difficulty. Differential hypothermia was produced by clamping the thoracic aorta and by cooling of the pulmonary circulation with refrigerated oxygen. In 13 dogs the temperature

Selective rewarming of the heart was attempted by diathermy,[20] by warm saline solution, and by a heating element in the esophagus.[21]

None of these procedures listed affected in any way the high mortality of dogs after short cessation of the circulation during hypothermia below 20° C. At present, the only clue to a possible solution for this difficulty, though not elucidation of the problem, lies in the administration of cortisone. After preliminary testing of various dosages in 12 dogs, the following schedule appears to be satisfactory. The day before the experiment the animals receive 100 mg. cortisone acetate intramuscularly, 100 mg. hydrocortisone intravenously before cooling, and 50 mg. cortisone acetate intramuscularly at night and during the following three days. Instead of water, the animals are given saline solution to drink.

The actual experimental procedure consists in a right thoracotomy at the time the heart rate has slowed down to about 16 beats per minute at about 20° C. When both caval and azygos vein are occluded, the temperature has drifted to 14° C. in the smaller animals and the heart is almost in standstill. After release of the venous occlusion, hyperventilation with oxygen is started again, the body is rewarmed by dry heat, and gentle massage of the heart is started to prevent dilatation of the right heart at such low temperatures. At first the femoral blood pressure does not have to exceed 20 to 30 mm. Hg, but when the temperature has risen to about 21° C. a higher blood pressure is desirable and at that time a remarkable increase in myocardial tonus can be achieved by a slow intravenous drip of 20 mg. of l-Arterenol in 500 ml. of a plasma expander. This unusually high concentration is chosen in order to derive the benefit of l-Arterenol without overloading the circulation. Even a comparatively small increase in blood volume at that stage will invariably cause pulmonary edema. When the heart rate has reached at least 30 beats per minute at about 22° to 23° C. the massage can be discontinued. The slow drip of plasma expander and l-Arterenol is continued throughout the slow rewarming procedure which takes four to five hours. Above 32° C. spontaneous respiration becomes dependable enough to stop the respirator, but oxygen is administered through the tracheal tube until the animal is awake.

In seven consecutive experiments (Table I), the circulation was interrupted from 10 to 15 minutes at temperatures from 18° to 14° C. The 2 dogs with a 15 minute inflow occlusion did not wake up, the 2 animals with 12 minute

TABLE I. VENOUS INFLOW STASIS DURING SEVERE HYPOTHERMIA IN CORTISONE TREATED DOGS

DOG NO.	WEIGHT (KILOGRAM)	TEMPERATURE (DEGREES CENTIGRADE)	HEART RATE (PER MINUTE)	DURATION INFLOW STASIS (MINUTES)	CARDIAC MASSAGE (MINUTES)	OUTCOME
1	7.3	14.0	2	15	38	Died
2	8.6	14.5	6	10	32	Lived
3	10.0	16.0	12	10	15	Lived
4	10.0	18.5	10	10	12	Lived
5	11.0	18.0	16	12	29	Lived
6	6.0	15.0	4	15	22	Died
7	10.0	16.5	12	12	24	Lived

inflow occlusion survived, but both still seemed to be under the effect of the narcotic the following day. This series is much too small to make a definite statement about the ultimate advantages of inducing profound hypothermia per se, but it appears as if the safe period of circulatory interruption cannot be extended beyond 12 minutes at body temperatures of 14° C.

SUMMARY

1. Differential hypothermia of 0° C. can be produced in dogs if the venous return is circulated, oxygenated, and refrigerated in a small plastic pump-oxygenator. This condition provides a bloodless field for prolonged open intracardiac surgery without the complications of anoxia, air embolism, or ventricular fibrillation.

2. Hypothermic cardiac arrest can also be achieved without extracorporeal circulation by the prevention of ventricular fibrillation with quinidine. Delayed shock following a severe anoxic insult at body temperatures below 20° C. can be prevented and treated by the vigorous administration of cortisone. At present it seems unlikely that the absolutely safe period of inflow stasis could be materially prolonged beyond 12 minutes at the temperatures employed, and therefore even severe hypothermia without extracorporeal circulation may aid in simple and short intracardiac surgery only.

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DISCUSSION

DR FLOYD J LEWIS, Minneapolis, Minn —I should like to congratulate Dr Gollan on his impressive use of a small heart lung machine to extend the range of hypothermia in these animals, but I particularly want to comment on his attempts to reach these lower temperature ranges without the small heart lung machine We are interested in the same problem As you will remember, he was able to achieve cardiac standstill in most of his animals cooled to temperatures below 12° or 10° C by giving them quinidine beforehand, and he encountered almost no ventricular fibrillation My associate, Dr Niazi, has not been able to achieve standstill in such a high percentage of dogs but when he has achieved it most of them have recovered, so I thought it would be worth while to mention the method that Dr Niazi has used in the laboratory There are a number of involved experiments and I will comment only on one type, in which dogs from 3 to 6 months of age, weighing around 20 pounds, were cooled while breathing 5 per cent carbon dioxide When the temperature got down to about 20° C, the carbon dioxide was stopped and they then shifted from slight acidosis into alkalosis, and at a lower temperature 17 out of 38 went into cardiac standstill This was the end we were trying to achieve Those 17 were all cooled below 10° C Finally they were rewarmed and 13 of the 17 are long term survivors So there is nothing intrinsic in these low temperatures that will result in late shock, such as Dr Gollan found in his dogs that were cooled without the heart lung machine

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(The Surgical Forum papers will be concluded in the December issue)

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-sixth Annual Meeting of the American Association for Thoracic Surgery will be held May 7, 8 and 9, 1956, in Miami Beach, Florida. Headquarters will be at the Hotel Fontainebleau.

Requests for Hotel Reservations

These should be mailed directly to Mr. Jack Stone, Director of Sales, Hotel Fontainebleau, Miami Beach, Florida. Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure. If accommodations are [illegible] hotels elsewhere in Miami Beach, please communicate directly with the hotel of your choice.

Thoracic Surgical Forum

The Thoracic Surgical Forum will be continued as a special session at the 1956 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers or to suggest their transferal to the Regular Program.

Papers at this session will be limited to ten minutes including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgical Forum papers will be published together in one issue of the [illegible]. Maximum length [illegible] words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Assocation must be received by the Membership Committee not later than Dec 15, 1955, otherwise, the applications will be deferred for consideration until the 1957 meeting

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

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(Concluded)

PHYSIOLOGIC OBSERVATIONS IN EXPERIMENTAL PULMONARY INSUFFICIENCY

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THE surgical attack upon isolated congenital stenosis of the pulmonary valve has been quite successful in relieving symptoms due to this disease. After transventricular valvulotomy (Brock technique)[1, 2] however, right ventricular pressures rarely return to normal and usually are in the range of 50 to 90 mm. Hg. Pressure studies at a Brock procedure upon an eighteen-year-old boy are illustrated in Fig. 1. Preoperatively, the right ventricular pressure was 128/0. After the first cutting and dilatation of the valve with Potts instruments the right ventricular pressure was 90/0. The valve was incised and dilated again with the instruments opened to the full extent but right ventricular systolic pressure could not be brought lower than 60 mm. Hg. The persisting [illegible]

Blount,[7] and their associates, feel that this probably is of no significance since the patients get along well and the electrocardiographic right ventricular strain pattern decreases. Also, Swan has observed dogs with insufficiency of the pulmonary valve for several years and no evidence of cardiovascular disturbance has developed.

Hufnagel[10] produced some degree of insufficiency of the pulmonary valve in dogs by means of a technique to correct pulmonary stenosis. During the fourteen-week observation period, no evidence of dilatation or hypertrophy of the right ventricle developed.

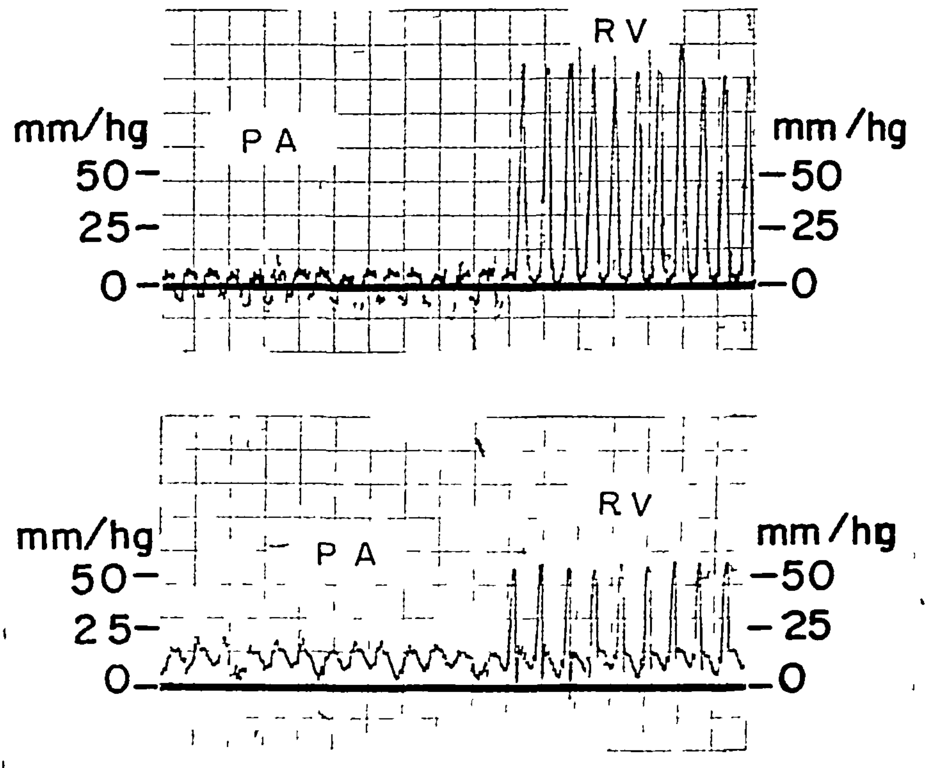
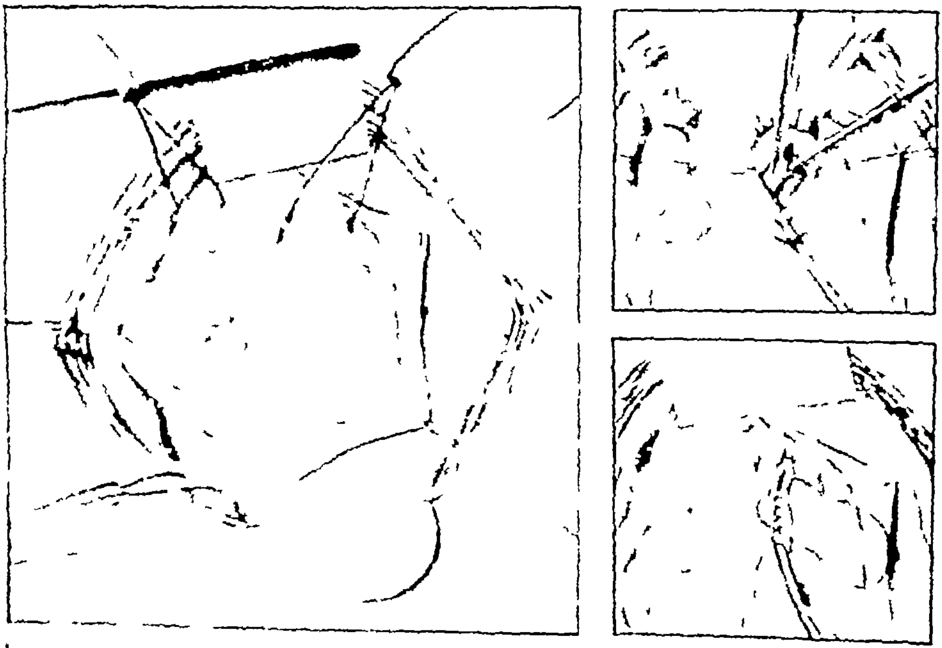


Fig 1.—*A* Preoperative cardiac catheterization record of an 18-year-old white man with isolated pulmonary stenosis. *B* Postvalvulotomy record made at surgery. Note persisting systolic pressure gradient across pulmonary valve and similarity between PA and RV diastolic contours suggesting regurgitation.

After relief of the obstruction by the transventricular approach in tetralogy of Fallot, patients sometimes develop right heart failure, presumably due to pulmonary insufficiency if the obstruction is completely removed.[11, 12] In pure pulmonary stenosis, Brock[13] feels that the obstruction may be relieved too greatly, resulting in serious insufficiency of the valve. He feels, too, that the effects of pulmonary insufficiency may be as serious as those of aortic insufficiency.

In order to inquire further into this problem the pulmonary valves were removed from a series of dogs. The animals survived with normal activity for months. The most striking abnormality aside from murmurs was a right ventricular systolic pressure that exceeded the pulmonary artery pressure by 2 to 40 mm Hg. This was seen in dogs whose pulmonary orifices were smooth, of normal size and lacking only the valves.

Some of the dogs were operated upon under hypothermia induced by immersion in an ice bath. When the rectal temperature reached 31° C the dogs were prepared for surgery. Usually the temperatures dropped 3° to 5° C further so that during surgery temperatures were 26° to 28° C. Ex



[illegible]

Six dogs were operated upon under normothermic conditions. The operative procedure was the same except that occlusion of the circulation was limited to 2 minutes. If excision of the valve was not completed in this time, the pulmonary artery defect was clamped and circulation re-established for 5 or 10 minutes. While the circulation was occluded for a second 2-minute period, removal of the valves was completed. Five of the 6 dogs survived without developing ventricular fibrillation. Autopsy of the dogs that died in each group revealed complete removal of the valves with no obstruction of the pulmonary artery as a result of its repair.

Thus, 10 dogs survived total pulmonary valvulectomy and have been observed from one to fourteen months. The animals were turned into a dog run about two weeks postoperatively and have led normal lives. All have done well clinically and none has presented evidence of heart failure. The first 4 dogs of the series, under observation for eleven months or longer, have gone through apparently normal pregnancies.

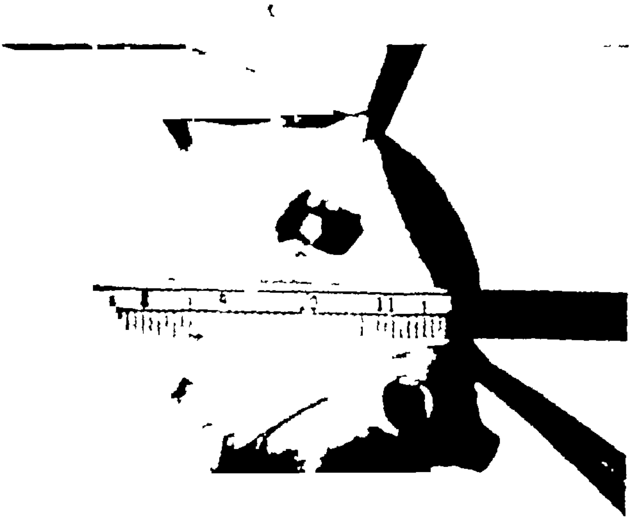
In all dogs, phonocardiograms confirmed the presence of Grade III systolic and Grades I to II diastolic murmurs. We regard these murmurs as hemic rather than stenotic, because there was no anatomic stenosis. The presumably very large tidal ejection seems to cause a turbulence in the pulmonary trunk that is responsible not only for the murmur but also for the energy loss that is indicated by the pressure drop seen when the catheter tip leaves the ventricle and enters the artery.

TABLE I. SUMMARY OF DATA ON DOGS WITH PULMONARY INSUFFICIENCY

DOG NUMBER	PERIOD OF OBSERVATION (MONTHS)	P.A. (MM HG)	R.V. (MM HG)	CARDIAC INDEX* FIRST AND LAST CATHETERIZATION	CARDIAC VOLUMES† PREOP AND LAST X RAY
HP 3	14	19/5	21/−3	2.2 – 2.7	542 – 463
HP-4	13½	11/3	23/1	5.6 – 4.6	403 – 359
HP 5	12½	30/2	70/3	2.9 – 1.8	440 – 310
HP 8	11	17/5	26/1	4.3 – 3.8	417 – 428
HP 10	1	28/−2	58/1	4.0	
NP 1	4	15/−1	20/−3	4.3	400 – 436
NP 2	4	14/1	33/2	4.0	455 – 533
NP 3	3½	25/3	33/4	3.8	458 – 342
NP 5	2½	29/3	37/3	4.3	365 – 623
NP 6	2½	21/1	30/1	4.5	453 – 593

*Liters per minute per square meter.
†Cubic centimeters per M body surface.

Cardiac catheterization was done at varying intervals after surgery. Some of the dogs have been catheterized three times while the more recent ones have been catheterized only once (Table I). In all cases, the right ventricular systolic pressure was greater than the pulmonary artery systolic pressure. This gradient averaged 15 mm Hg for the 10 dogs with a range of 2 to 40 mm Hg. One of these (HP-10) had a pulmonary artery systolic pressure of 28 mm Hg and a right ventricular systolic pressure of 58 mm Hg. This dog was sacrificed at one month and autopsy showed an unobstructed pulmonary orifice. The right ventricular wall was questionably thickened. The other dog with high right ventricular systolic pressure (HP-5) was followed



for twelve and one-half months At five months after operation, catheterization revealed a right ventricular systolic pressure of 61 mm Hg and at ten months this pressure was 70 mm Hg Clinically the dog did well and presented no evidence of disturbance in circulation when sacrificed twelve and one-half months after surgery Autopsy revealed no evidence of obstruction at the site of the pulmonary valves and the right ventricle was questionably hypertrophied (Fig 3, *A* and *B*)

Pulmonary artery diastolic pressures were uniformly low, ranging from 0 to 5 mm Hg In no case was a normal diastolic pressure recorded The pulmonary artery and right ventricular pulse contours resembled each other

Right ventricular end-diastolic pressures were normal in all cases

Cardiac outputs by the Fick method were essentially normal and no particular difference between the early and late cardiac indices was observed In one case (HP-5), catheterization ten months after valvulectomy revealed a low output (cardiac index = 1 8), but no particular significance was attached to it because the dog presented no evidence of failure

Measurement of heart volumes by x-ray,[14] as indicated in Table I, showed a significant increase in only 2 dogs Both of them have been followed two and one-half months since surgery One (NP-6) had a 30 per cent increase and the other (NP-5), a 70 per cent increase in heart volume Both of them are doing well

Electrocardiograms likewise were made preoperatively and at frequent intervals postoperatively In no case was any evidence of right ventricular strain or hypertrophy present even though the 2 dogs autopsied showed suggestive hypertrophy

DISCUSSION

The demonstration of a pressure gradient across the pulmonary orifice would ordinarily suggest a stenosis in this region Autopsy of the two dogs which showed the largest RV-PA pressure gradient showed, however, that no such obstruction existed The pressure drop must be explained as a result of something other than a stenosis Kohout and Katz[15] recently reported a patient with pulmonary valvular insufficiency diagnosed by cardiac catheterization Likewise, as in our dogs, the diastolic pressures in the pulmonary artery and right ventricle were similar and a systolic gradient was recorded across the valve area

The amount of blood ejected during systole must be abnormally large because it includes the regurgitated blood as well as that coming through the tricuspid valve Velocity of flow through the pulmonary artery would therefore be very great and, *as indicated by the strong systolic murmur, the flow* must be turbulent The acceleration of the column of blood in the pulmonary artery to an unusually high velocity with its creation of turbulence in the stream may account for the pressure drop even in the absence of a demonstrable stenosis

In a clinical study of atrial septal defects, Blount and co-workers[16] demonstrated a systolic pressure gradient across the pulmonary valve *He attributed*

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DISCUSSION

DR FRANK GERBODE, San Francisco, Calif —We have been interested in pulmonic stenosis because we have found a number of adults who have a very high right ventricular pressure and a very tight and hard valve This valve can be cut and dilated in the way described by Brock and others, but the pressures do not always fall because the valve lacks elasticity Some are almost cartilaginous in nature, and I believe they become that way because of the flow and turbulence caused by the stenosis itself In other instances, the valve becomes more stenotic and hard because of fibrosis resulting from endocarditis Obviously, some other means, as has been pointed out by Swan, must be called upon to cut these valves We have done so in a number of these unusual instances by simply biting out a piece of valve with a small Brock punch valvulotome, it being necessary to do this in order to obtain a reduction in ventricular pressure

These findings led to a study of pulmonic insufficiency in the laboratory We have 10 animals under observation who have had total removal of the pulmonary valves We too have found that pulmonary insufficiency is a relatively benign lesion in a normal animal These animals run around the laboratory, act quite normally, and do not seem to get heart failure However we must, I believe, reserve our opinion on this matter of total excision of the pulmonic valve until we have made observations under stress and over a longer period of

EXPERIMENTAL TRANSPOSITION OF THE GREAT VESSELS SOME FACTORS WHICH INCREASE THE FLOW THROUGH THE ATRIAL SEPTAL DEFECT

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A PARTIAL transposition was created in dogs by the following 3 procedures (1) an artificial interatrial septal defect, (2) an anastomosis between the distal cut end of the right superior pulmonary vein and the proximal end of the azygos vein and, (3) an end-to end anastomosis between the brachiocephalic artery and right pulmonary artery (Fig 1) The purpose of this paper is to describe methods and results of increasing the right-to-left shunt through the atrial septal defect The preparation just described is called the Type I since we have also created experimental transposition in another manner A complete report on the Type I and Type II preparations will be presented in a separate communication

METHODS AND RESULTS

Adult mongrel dogs were used They were anesthetized with sodium pentobarbital given intravenously Mean blood pressures were determined by inserting a needle which was connected to a mercury manometer into the femoral artery During the catheterization of the heart, the blood pressure was recorded using strain gauges with a 2 channel Sanborn Visocardiette Later studies were made with an optical recording oscillograph The blood oxygen determinations were made with the Van Slyke-Neill apparatus

The Type I Preparation —After the right chest was opened through the bed of the fourth or fifth rib, an interatrial septal defect was made by the method of Swan and co-workers[8] in 12 of the 14 dogs included in this report The divided distal end of the right superior pulmonary vein was anastomosed to the proximal end of the azygos vein The proximal end of the pulmonary vein was closed by suture, the distal end of the azygos vein was ligated The proximal end of the divided brachiocephalic (innominate) artery was then sutured end-to-end to the right pulmonary artery creating an artificial ductus arteriosus The proximal end of the right pulmonary artery was ligated By this arrangement, pulmonary vein blood from the right apical and cardiac lobes is diverted into the right auricle via the azygos vein and superior vena cava There is an increase in flow in the right superior and inferior pulmonary veins due to the connection of the right pulmonary artery to the aorta via the brachiocephalic

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artery. The increase in flow into the left heart from the right inferior pulmonary vein tends to balance the additional flow into the right heart. To avoid repeated description of the operation this will be called the Type I preparation (Fig. 2).

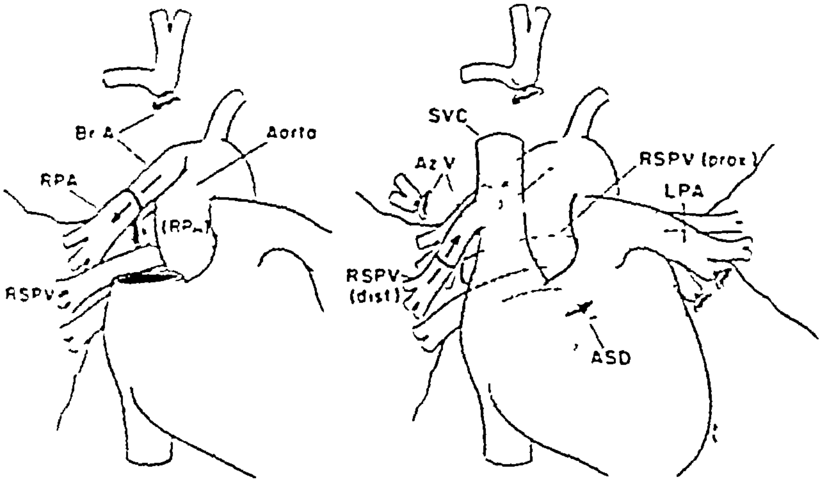
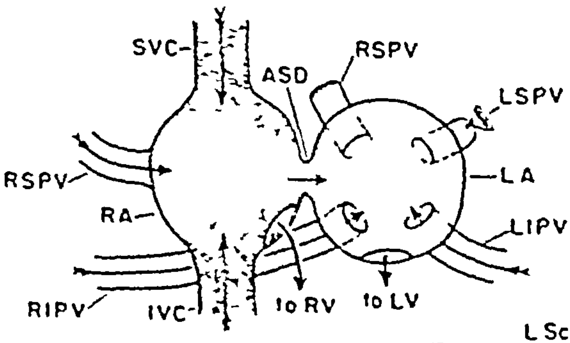


Fig. 2.—Diagram of the Type I preparation. Br A, Brachiocephalic artery; RPA, Right pulmonary artery; RSPV, Right superior pulmonary vein; SVC, Superior vena cava; Az V, Azygos vein; ASD, Atrial septal defect; LPA, Left pulmonary artery.



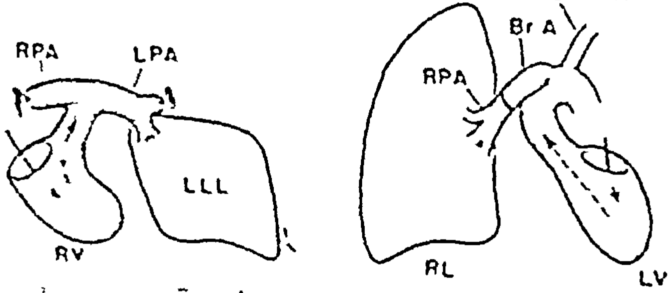


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TABLE I EFFECT ON ARTERIAL OXYGEN SATURATION OF TEMPORARY OCCLUSION OF THE LEFT PULMONARY ARTERY IN ANIMALS WITH THE TYPE I PREPARATION

	TIME	DOG 300 (2/6/53)	TIME	DOG 300 (2/13/53)	TIME	DOG 302 (2/4/53)	TIME	DOG 299 (2/17/53)	TIME	DOG 305 (3/13/53)	TIME	DOG 317 (5/16/53)
		(%)		(%)		(%)		(%)		(%)		(%)
Control arterial oxygen Breathing air		77		72		76		57		71		80
Control arterial oxygen Breathing oxygen												85
After occlusion of LPA	8½ min	65	2 min 20 sec	66	55 sec	55	2 min 10 sec	59	2 min	49 8	1 min	69
After release LPA			5 min	71				80		80		
After reocclusion LPA	1½ min	54			75 sec	57						
After release LPA	3 min	66										
After reocclusion LPA					2½ min	59						

Dog 300 was under local anesthetic only closed chest breathing air All others were under Pentothal sodium anesthesia open chest breathing 100 per cent oxygen with positive pressure

Dog 302 had intact left lung Dog 305 had left inferior lobectomy Dogs 299 300 and 317 had left superior lobectomy

Time indicates period of occlusion of artery

All 12 of the animals with the Type I preparation became cyanotic. The arterial oxygen saturation was measured in 6 dogs while breathing air without anesthesia. The average of 10 determinations was 70.5 per cent (range 57 to 80 per cent).

Three methods were used in the Type I preparations to increase the right-to-left shunt through the atrial septal defect. The first 2 methods were studied in acute experiments, the last was observed in chronic experiments. These were (1) left pneumonectomy, (2) temporary occlusion of the left pulmonary artery, and (3) excision of a lobe of the left lung.

The degree of cyanosis as measured by the arterial oxygen saturation is used as a rough estimate of the volume of the right to left shunt. Pulmonary hypertension consistently developed in the dogs which were maintained up to two years, however, presentation of those results will largely be deferred in order to simplify this presentation.

1. *Left Pneumonectomy (Experimental Pulmonary Atresia)*.—The effects of left pneumonectomy were of interest since ligation of the left pulmonary artery prevents any output from the right heart except through the interauricular septal defect. In 4 animals prepared with the Type I operation pneumonectomy was performed. Two of these dogs had an interatrial septal defect and 2 did not. The 2 animals with an intact atrial septum promptly developed ventricular fibrillation when the left pulmonary artery was clamped. The 2 animals with an interatrial communication lived for two and one half and six hours after left pneumonectomy. At autopsy the right lung was congested and the bronchi and trachea contained white foam. It will be shown later that there is an immediate fall in the arterial oxygen content which must be a factor in the death of the animals. Right ventricular failure is another factor. When the right and left pulmonary arteries are completely occluded the atrial septal defect permits some emptying of the right ventricle. The survival for several hours of these 2 dogs is thus explained. If an interventricular septal defect was made one would anticipate that longer survival would be possible. This condition corresponds to that seen clinically as *pulmonary atresia*.

Dog 305 had a left inferior lobectomy, and Dog 302 had an intact left lung It was demonstrated in the experiments just described, in which pneumonectomy was performed, that occlusion of the left pulmonary artery, pulmonary veins, and bronchus may be tolerated for several hours if an interatrial septal defect is present Arterial blood samples were drawn from the femoral artery in Dog 300 and from the aorta in the remainder

A fall in the arterial oxygen saturation followed occlusion of the left pulmonary artery in all the animals Presumably this is produced by an immediate increase (within 55 seconds) in the right-to-left shunt through the atrial septal defect The greatest reduction occurred in Dog 305 which had the larger inferior lobe resected (24 per cent of lung tissue compared to the upper lobe which constitutes 16 per cent[5])

Evidence that the fall in arterial oxygen content was not due to a general deterioration of the condition of the animal but to an increase in the right-to-left shunt through the patent atrial septum is derived from measurements of the systemic blood pressure before, during, and after the left pulmonary artery was occluded (Table II) A rise in blood pressure was noted in the 2 animals in which these studies were made One was under sodium pentobarbital anesthesia, with 100 per cent oxygen administered through an endotracheal tube with open thoracotomy, the other experiment was under local anesthesia with a closed chest, the animal breathing air An early increase in the systemic blood pressure could be explained by the acute effect of anoxia producing vasoconstriction Eventually right ventricular failure, due to inability to empty adequately, would result in a fall in cardiac output and blood pressure This factor would then contribute to the hypoxemia Left ventricular failure might also occur late but would not account for the rapid fall in arterial oxygenation It is doubtful whether the systemic blood pressure would have remained normal had the experiments continued for several hours

TABLE II EFFECT ON ARTERIAL BLOOD PRESSURE OF TEMPORARY OCCLUSION OF THE LEFT PULMONARY ARTERY IN ANIMALS WITH THE TYPE I PREPARATION

DOG 302 (2/4/53) PENTOBARBITAL ANESTHESIA, OPEN CHEST 100% O_2 POSITIVE PRESSURE		DOG 300 (2/6/53) LOCAL ANESTHESIA, CLOSED CHEST BREATHING AIR	
TIME (MINUTES)	MEAN BP AORTA (MM Hg)	TIME (MINUTES)	BP FEMORAL ARTERY (MM Hg)
Control	*64*	*Control*	*120/80*
0	LPA clamped	0	LPA occluded
½	64	4	120/80
1½	80	6	105/80
2	100	8½	135/80
4	LPA released	8½	LPA released
4	120	11	115/85
6	120	15	110/85
7	102	15	LPA reoccluded
9	100	16½	160/85
		18	LPA released
		18½	150/90

3 *Lobectomy*—In 6 animals, a lobectomy of the left lung was performed The inferior lobe (larger) was resected in 2 and the superior lobe in 4 animals

These procedures were well tolerated. The arterial oxygen saturation was determined in 1 dog of this group before and after left superior lobectomy. In Dog 609, there was no apparent effect (75 per cent before lobectomy; 77 and 72 per cent two months after lobectomy). The relation of the reduction in the vascular bed by left lobectomy to the development of cyanosis or pulmonary hypertension will be mentioned later under Discussion. Experimental data to show the effect of reduction of the vascular bed are included in the preceding section concerning the effects of temporary occlusion of the left pulmonary artery.

DISCUSSION

Survival of dogs with experimental pulmonary atresia (right lung supplied with blood from aorta via right pulmonary artery and left pulmonary artery divided at a second stage) depends on the right ventricle being able to empty itself via an atrial or ventricular septal defect or both. A reverse flow ductus is another possible way for the right ventricle to empty. In our experiments only an atrial septal defect was created.

The concept of experimentally forcing a greater flow from right to left through an atrial septal defect by increasing the resistance to the outflow of the right ventricle has a clinical analogy. In clinical cases of pulmonic stenosis associated with a patent foramen ovale or an atrial septal defect, severe degrees of cyanosis have been observed.[6] After relief of the pulmonic stenosis the cyanosis is reduced. In both experimental and clinical examples the preoperative pressure in the right ventricle and right atrium is elevated and increases the right to left shunt.

Temporary occlusion of the left pulmonary artery in the Type I preparation was followed by an immediate and pronounced fall in arterial oxygen saturation. This reproduces the condition long observed clinically of cyanosis produced by crying, pneumonitis, etc., which raise the pressure on the right side of the heart or in the pulmonary artery. This was emphasized by Maude Abbott[1] when she classified patent ductus and septal defects as "cyanosis tardive."

They found that the creation of a large atrial septal defect, together with an anastomosis between the subclavian and pulmonary arteries, was followed by the greatest improvement in their patients They also noted in their series that a patient who happened to have a mild pulmonic stenosis and therefore theoretically a greater right-to-left shunt as well as transposition of the great vessels had the most striking improvement

SUMMARY

1 Partial transposition of the great vessels has been created by end-to end anastomosis between the right superior pulmonary vein and the azygos vein and between the brachiocephalic artery and right pulmonary artery In addition, an atrial septal defect is created

2 The right-to-left shunt was increased in this preparation by three methods (1) left pneumonectomy (corresponds to experimental pulmonary atresia), (2) temporary occlusion of the left pulmonary artery (corresponds to Abbott's "cyanosis tardive"), and (3) excision of a lobe of the left lung (corresponds to pulmonary destruction and cor pulmonale)

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The result of these observations made during the use of controlled cross circulation in the clinical operating room was the realization that, especially in the infants and small children, the total amount of blood exchanged during the perfusion period was relatively small and conceivably could be provided by a reservoir instead of a donor This suggested further investigation of a reservoir method of perfusion that we had employed to a limited extent in the laboratory some 12 to 14 months before By the use of this method in conjunction with the concept of reduced flow and the mechanical principles of controlled cross circulation (which insured a quantitative balance between the arterial perfusion and the venous withdrawal from the recipient) it was possible to occlude the cardiac inflow and provide ample opportunity to operate within the chambers of a dry heart and at the same time to simplify the procedure

METHOD

The arrangement of the extracorporeal circuits is expressed diagrammatically in Fig 1 In general, the setup is similar to that employed in the controlled cross circulation technique[1] with the exception that the donor is replaced by an arterial *(A, 1* and *2)* and a venous *(V, 2* and *3)* reservoir These are merely siliconized Baxter Plasma Vac bottles (500 c c or 1,000 c c) from which the vacuum has been exhausted Bottles *A, 1* and *2* contain arterial blood that has been collected previously in the manner described below *V, 2* and *3* are empty at the outset and are provided to collect the venous blood withdrawn from the patient during the perfusion

It will be noted that the cannulations in the patient and their attachments to the pumping device are identical with those already described for use in controlled cross circulation These may be seen in the diagram of the heart where it will be noted that a cannula has been inserted into and passed down the right subclavian artery until the tip lies in the ascending aorta It is through this cannula that arterial blood from the reservoir enters the patient's arterial system Also, it will be noted that a Rumel tourniquet has been placed about the base of the aorta in order to provide a means for intermittent occlusion if the aortic valves are found incompetent when the heart is open. In addition, in this same diagram, it will be noted that cannulae have been passed through the right auricular wall and into the superior and inferior venae cavae, respectively These are secured by purse-string sutures at their points of entrance into the auricle and are joined at their distal ends to a "Y" adaptor During the period of cardiac by-pass, when the umbilical tapes about the superior and inferior venae cavae are drawn up about their respective cannulae, venous blood will be channeled from the patient's caval system into these cannulae and none will enter the heart

The extracorporeal circuits are assembled by first attaching two bottles of arterial blood to an ordinary blood filter* *(A, 3)* and allowing blood to fill the filter chamber while the latter is held in the inverted position so that all air will be displaced The outflow of the filter is then attached to the afferent plastic tube of the arterial pump *(A, 4)* The pump is then turned on momentarily so that the entire arterial circuit is filled with blood When this is done and the venous circuit is assembled as diagrammed, the appropriate connections can be made to the patient's cannulae and perfusion begun In practice, the arterial pump draws blood from only one bottle at a time When the first bottle is nearly empty, as, for instance, *A, 2* in the diagram, its outflow is clamped, that of *A, 1* is released and perfusion goes on uninterrupted while *A, 2* is being replaced by a full bottle of arterial blood This procedure is repeated until the pump is stopped Similarly, on the venous side when V 2 is full the venous outflow from the pump is diverted into V 3 while V 2 is replaced by another empty bottle

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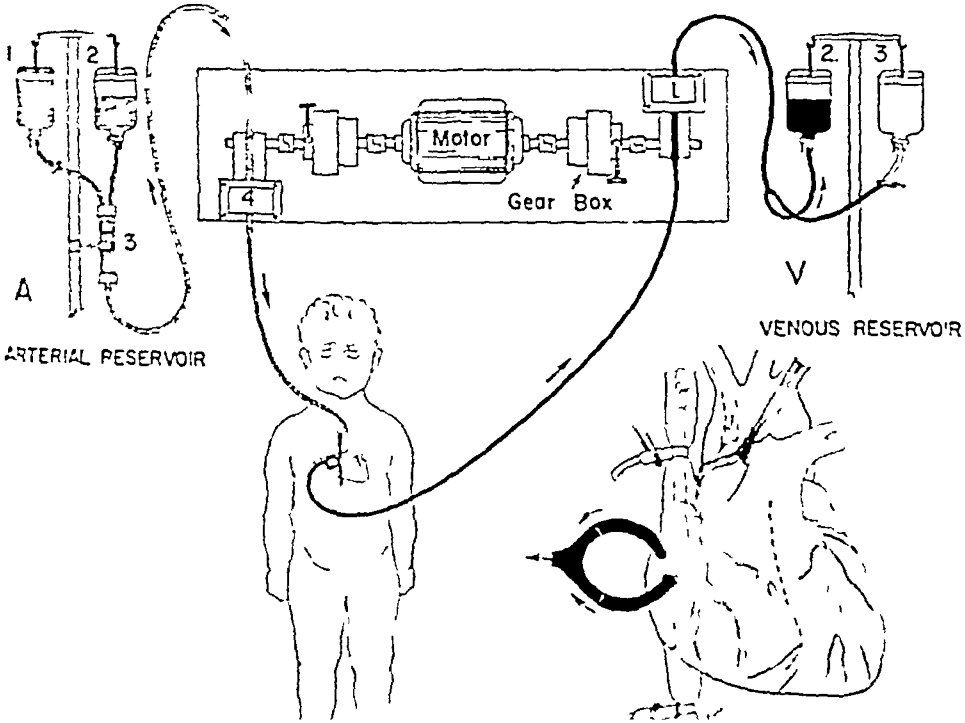
*Baxter Laboratories Morton Grove Illinois Filter R-19

The output of each pump is preset at equal rates before the pump is brought to the operating room It is desirable to check this calibration just prior to the onset of perfusion This is done under sterile conditions using a 5 per cent glucose solution in order to avoid the waste of blood



by the citric acid and the toxicity of citrated blood on the myocardium. At the outset, we adopted the amount of heparin frequently used for exchange transfusions which ranged between 50 and 75 mg. per 500 c.c. of blood. This amount was quite satisfactory with respect to the preservation of the blood, but it produced abnormal postoperative hemorrhage in all of the animals.[4] By further study, the optimum amount of heparin to prevent in vitro clotting without abnormal postoperative hemorrhage in the animal was found to be 15 to 17 mg. per 500 c.c. of blood, with marginal limits at 12.5 and 20 mg. In order to enhance mixing, this amount of heparin was added to 50 c.c. of 5 per cent glucose solution and was instilled in each 500 c.c. siliconized bottle after removal of the vacuum. This amount provided adequate protection against clotting with relatively good preservation of the cellular components over a fairly long period of time and under varying conditions.

Ordinarily, the arterial blood utilized for the perfusions has been collected within 2 to 4 hours of the time it was used. During this intervening period, it has been kept in a water bath at 38° C. to obviate the previously described deleterious effects on the heart of perfusion with cold blood.[3] However, it would seem reasonable to anticipate that storage for a prolonged period might be desired. In this event, the comparison of the depreciation noted when blood was maintained at room temperature (Table I) to that which occurred when stored at 4° C. (Table II) indicated that refrigeration was preferable for longer periods of storage. Inspection of these data revealed a rapid deterioration of the pH and oxygen content in the blood at room temperature over a few hours whereas the cold blood was stable, particularly with reference to the pH, for a much longer time. The platelets on the other hand tended to show a steady decline regardless of the mode of storage. The apparent inconsistency of the last count in Table II can be ascribed only to the wide margin of error inherent in platelet counts.

TABLE I. ARTERIAL BLOOD (HUMAN) COLLECTED IN HEPARIN* AND STORED AT ROOM TEMPERATURE

STORAGE TIME	pH	O (VOL. %)	CO (VOL. %)	HEMOGLOBIN	PLATELETS
Control	7.52	17.60	50.30	12.7	584,000
1 hour	7.51	18.00	43.98		410,000
2 hours	7.49	17.21	44.46		382,000
3 hours	7.48	16.6	43.10	12.0	298,000
4 hours	7.41	16.0	42.02		320,000
5 hours	7.35	16.88	42.67		344,000

*15 mg. heparin in 50 c.c. 5 per cent glucose per 500 c.c. blood.

TABLE II. ARTERIAL BLOOD (HUMAN) COLLECTED IN HEPARIN* AND STORED AT 4° C. TEMPERATURE

STORAGE TIME	pH	O (VOL. %)	CO (VOL. %)	HEMOGLOBIN	MEAN PLATELETS COUNT
Control	7.52	20.12	47.53	14.2	368,000
1 day	7.46	20.67	48.67	14.5	102,000
2 days	7.40	20.27	48.25	14.4	63,000
4 days	7.28	20.45	47.36	14.1	65,000
6 days	7.17	20.15	46.50	15	125,000

*20 mg. heparin in 25 c.c. 5 per cent glucose per 500 c.c. blood.

The mechanism by which this arterialization of venous blood occurs is the result of a local increase in rate of circulation[10] and the opening up of multiple small arteriovenous anastomoses in response to the increased temperature of the extremity.[11] [12] Furthermore, the value of these physiologic observations was increased when through experimentation it became evident that by continued heating of the arm the resultant arterial character of the venous blood could be maintained for protracted periods. By adapting these observations to our needs, a simple method of obtaining large volumes of arterialized blood evolved as follows. The arm of the prospective donor was immersed in a water bath at 45° C. for 15 to 20 minutes. To facilitate collection he was then asked to recline on a cot and the water bath was replaced by hot packs maintained at approximately 45° C. in order to maintain the local hyperthermia during the collection. Then, by means of a simple venepuncture in the antecubital fossa, 500 c.c. of arterialized venous blood was collected by gravity from each donor in the fashion previously described.

The volume of blood collected in preparation for a given operation was determined by the flow rate desired, the size of the patient, and the estimated length of perfusion needed. In the clinical case described below approximately 4,000 c.c. of arterialized venous blood was drawn in the above fashion.

CASE REPORT

L. O., U. H. No. 880964, a 6 month old male infant, entered the hospital on March 8, 1955. His parents stated he was well until the age of 3 months when his weight gain fell off and a heart murmur was heard on physical examination. In addition he had a history of frequent respiratory infections and dyspnea during the interval between 3 and 6 months of age.

Physical Examination.—There was a definite systolic thrill palpable over the precordium, being most noticeable in the left third and fourth interspaces, and a Grade IV harsh systolic murmur was also best heard in this area. The pulmonic second sound was greater than the aortic second sound. The liver margin was palpable 3 cm. below the right costal margin. A right cardiomegaly and increased pulmonary vascular markings were noted on x ray examination of the chest. Cardiac catheterization revealed a jump in the blood oxygen saturation of 22 per cent between the right atrium (62 per cent) and the right ventricle (84 per cent) and a pressure of 45/0 mm. Hg in the outflow tract of the right ventricle. These findings indicated an interventricular septal defect.

On March 29, 1955, the patient was operated upon and a high interventricular septal defect, approximately 1 cm. in diameter, was found and closed under direct vision by using the multiple interrupted suture technique.[13] During the 14 minutes and 45 seconds of total cardiac by-pass necessary to close this defect, the patient (weight 4.8 kilograms) was perfused at a rate of 150 c.c. per minute (31 c.c./kg./min.) by means of the described reservoir method. Arterialized venous blood for the arterial reservoir had been drawn a few hours preoperatively in the blood bank from 8 compatible donors whose arms had been heated to 45° C. for 15 minutes prior to collection. A total of 3,950 c.c. was drawn in this fashion and available for perfusion, however, only 2,225 c.c. were needed. His postoperative laboratory studies revealed a platelet count of 189,000 and normal bleeding and clotting times with a hemoglobin of 13.4 Gm. The loss from the chest catheters yielded only 110 c.c. of serosanguineous fluid during the first 48 hours. Postoperatively, the patient's convalescence was smooth and uneventful. The cardiac murmur and thrill have disappeared.

To date, this method of reservoir perfusion for total by pass of the heart and lungs for as long as forty five minutes has been utilized successfully in 5 patients with various types of intracardiac defects

The patient herein reported was seen recently in the Outpatient Department on Oct 10, 1955 He had gained 7 pounds 10 ounces over his preoperative weight, was active without limitation, has been free of intercurrent illness, and was developing normally in marked contrast to his preoperative status On physical examination no thrills or murmurs were present and on x ray examination of the chest a regression of the pulmonary vascular pattern to normal limits was evident

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DISCUSSION

DR RAYMOND C READ, Minneapolis, Minn —I should like briefly to supplement Dr Warden's presentation by describing the chemical characteristics of arterialized venous blood taken from the antecubital vein following warming of the hand and forearm

(slide) These are samples drawn from individual donors whose blood was used in a human case One can see that the oxygenation, CO_2 concentration, and pH are essentially the same as found in the artery The blood was drawn after immersing the donor's arm in water at 45° C for 10 minutes

THE ARTERIALIZATION OF BLOOD AS IT APPLIES TO THE MECHANICAL HEART-LUNG APPARATUS

F D Dodrill, M D, Alfred Lui, M D, (by invitation), Jan Nyboer, M D
(by invitation), E V Rippingille (by invitation), and
C H Hughes, B S (Med Biol) (by invitation)
Detroit, Mich

THERE is a very great need for a method of arterialization of the blood as it is passed through a pumping device so that the total venous return from the heart can be diverted through such an apparatus and returned to the arterial system as good arterialized blood There are two principal methods by which this can be accomplished The blood can be spread out as a thin sheet of red cells which are exposed to oxygen and which also allows the escape of the carbon dioxide This involves a large cross sectional area and in order to fill such a device large quantities of blood are required With the use of such an apparatus, the total blood volume in smaller animals and in patients is completely removed as donor blood replaces it The other way by which the blood may be arterialized is by the gaseous dispersion of oxygen through the blood This brings a huge number of small oxygen bubbles through the blood so that instead of spreading out the blood in a large film, the oxygen is spread out over a large surface area The former method has been extensively investigated by Gibbon and his associates[1] The latter method has been extensively investigated by Clark, Gollan, Gupta,[2] and others The latter investigators used porcelain plates and bacteriologic filters It is the purpose of this manuscript to report a different type of dispersion arterialization

THE ARTERIALIZER

Oxygen is passed upward through a stainless steel plate which is perforated with numerous tiny holes of 10 microns in diameter, Fig 1 The completely assembled apparatus is diagrammatically illustrated in Fig 2 Oxygen, which enters at *A*, is provided at a given pressure below the plate, *C*, which is placed transversely The tiny oxygen bubbles emerge from the top of the plate and are brought in contact with the blood Blood enters the bottom of the apparatus, *B*, where it produces a swirling motion throughout the annular surface of the chamber During this swirling motion, the blood and the tiny bubbles are brought in close approximation The metallic cylinder, *D*, is simply a variable space-occupying piece of metal which forces the blood and oxygen to pass up the annular surface, *E* As the blood and oxygen mixture reaches the level *F*, annular perforations are present at this point whereby the blood enters the coalescent chamber, *G* Here it is in contact with organo polysiloxane which

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From the Research Division of Harper Hospital and the Research Laboratories Division General Motors Corporation

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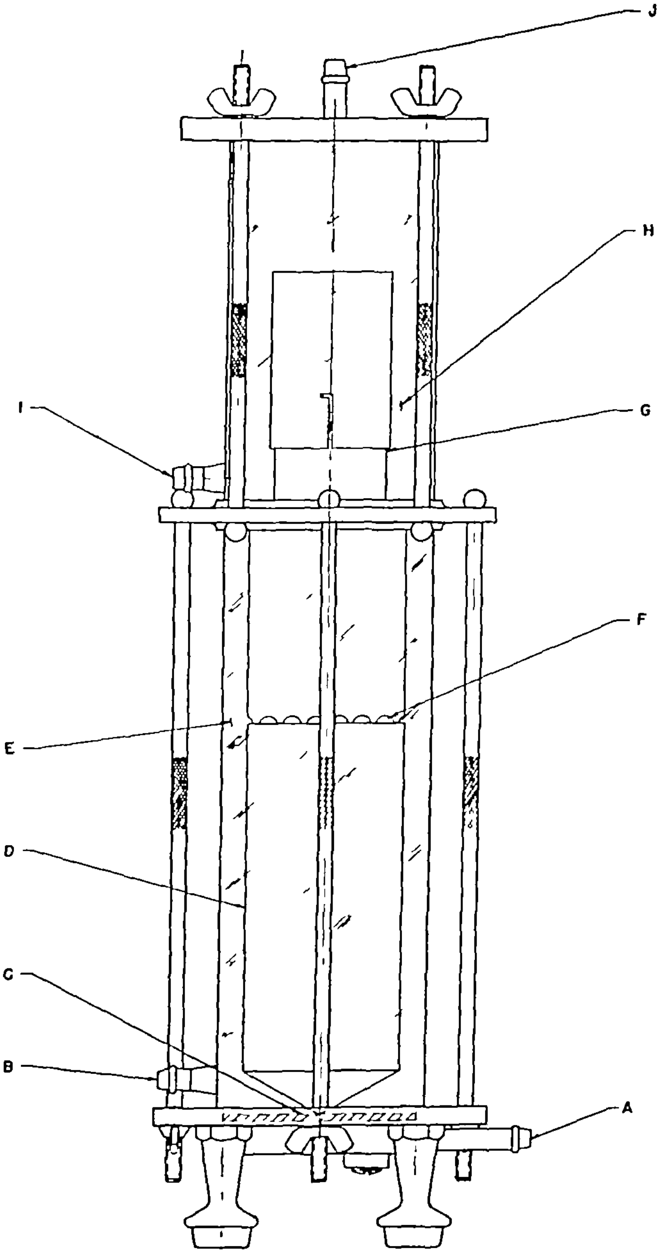
the lungs are situated between the right and left heart The right side of the pump removes the blood from the venae cavae, pumps it through the arterializer and the left side of the mechanical heart picks up the arterialized blood and returns it to the arterial system Figs 3A and 3B illustrate the total apparatus consisting of the two sides of the pump together with the arterializer

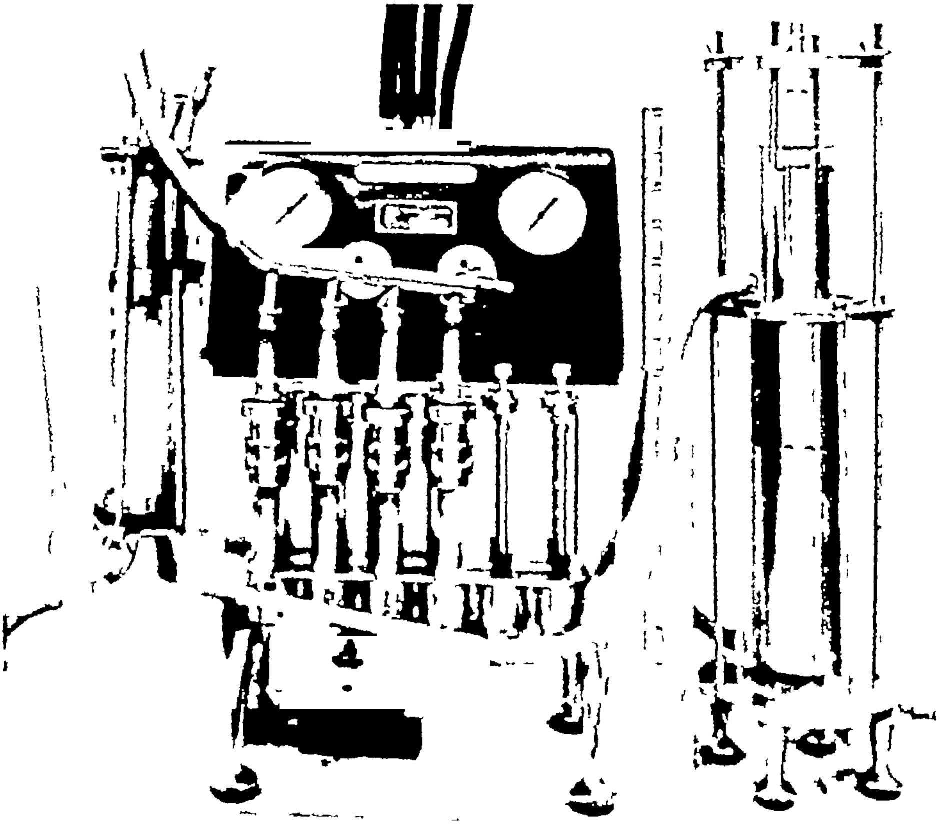


APPARATUS FOR THE ARTERIALIZATION OF BLOOD

Fig 2.

RESULTS OF EXPERIMENTS

The apparatus is connected to the animal by cannulating both venae cavae for the inflow and the left subclavian artery and left femoral artery for the outflow. The venae cavae are ligated around the tubes and the azygos vein is occluded. All return to the right heart must therefore pass through the apparatus. Extensive determinations of the arterial oxygen saturation, carbon dioxide content and pH of the arterialized blood have been made. In addition, blood counts, platelet counts, and fragility tests have been made.



circulation so that arterialization in excess of 100 per cent saturation is common. We believe that minute bubbles of oxygen are not present in the blood as it escapes from the arterializer. In the event that free bubbles could be present, however, there is adequate provision for them to escape as the blood passes through the left side of the mechanical heart and through the flowmeter and bubble trap. It can be seen from the graph on the oxygen saturation that out of approximately 30 determinations in 10 experiments, practically all are of satisfactory saturations.

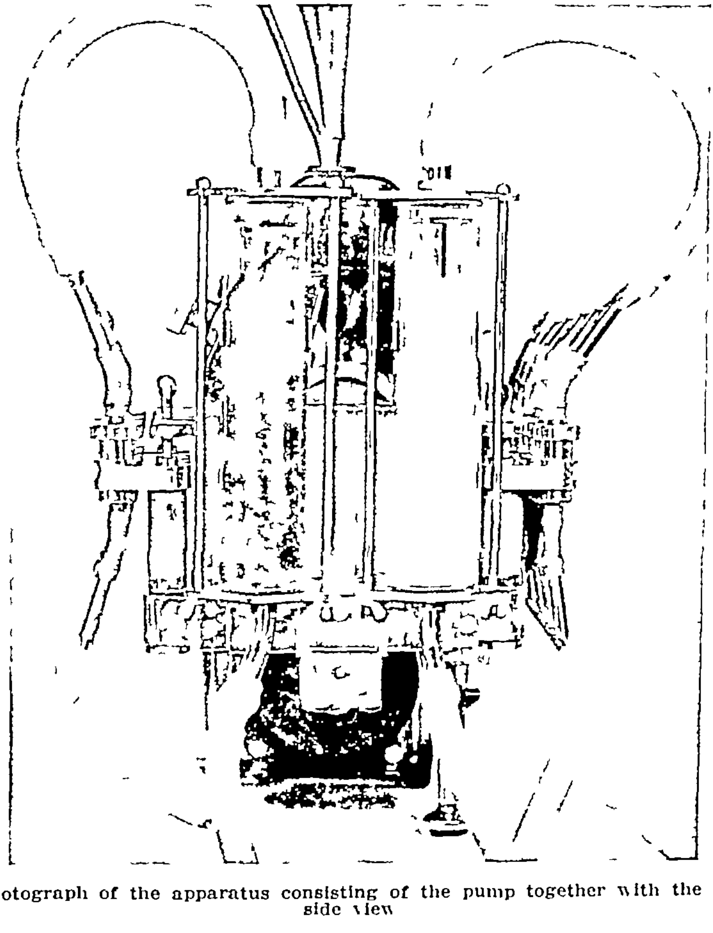


Fig. 3B.—Photograph of the apparatus consisting of the pump together with the arterializer side view.

Carbon Dioxide Content.—With the use of 98 per cent oxygen and 2 per carbon dioxide, excess carbon dioxide is not removed as it passes through the arterializer so that the arterialized blood contains essentially normal carbon dioxide. Fig. 5 illustrates the arterial carbon dioxide in volumes percentages during 30 minutes of total by-pass. It can readily be seen that of approximately 30 determinations only a few can be regarded as abnormal.

pH Determinations.—Fig. 6 illustrates a scatter graph in which 10 experiments are carried out during which time approximately *30 determinations of*

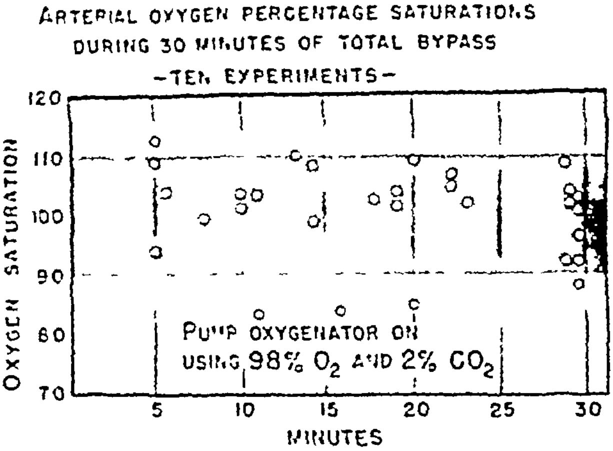
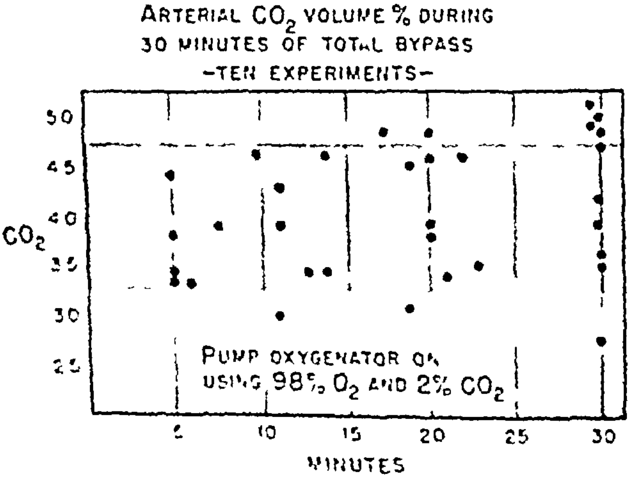

ARTERIAL OXYGEN PERCENTAGE SATURATIONS
DURING 30 MINUTES OF TOTAL BYPASS
-TEN EXPERIMENTS-
OXYGEN SATURATION
120
110
100
90
80
70
PUMP OXYGENATOR ON
USING 98% O2 AND 2% CO2
5
10
15
20
25
30
MINUTES

Fig. 4


ARTERIAL CO2 VOLUME % DURING
30 MINUTES OF TOTAL BYPASS
-TEN EXPERIMENTS-
CO2
50
45
40
35
30
25
PUMP OXYGENATOR ON
USING 98% O2 AND 2% CO2
5
10
15
20
25
30
MINUTES

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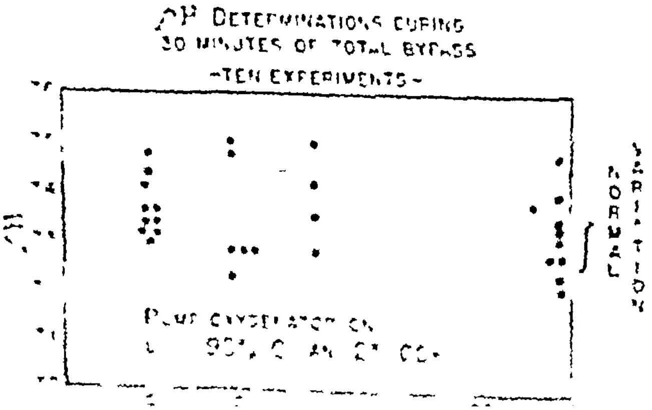
pH DETERMINATIONS DURING
30 MINUTES OF TOTAL BYPASS
-TEN EXPERIMENTS-
pH
NORMAL
VARIATION
PUMP OXYGENATOR ON
USING 98% O2 AND 2% CO2

[illegible]

the pH are made at approximately 5 minutes, 10 to 15 minutes, and at 30 minutes' duration. A glance at the graph shows that for a 30-minute period of complete by-pass the pH remains within normal limits. It is interesting to note that the pH of the blood of the dog, after it has been anesthetized, the chest has been opened, and it is on forced respiration, shows a tremendous variation. We usually find at this time that the pH may be greatly elevated to 7.6 or 7.8 but that immediately after it passes through the apparatus it has been reduced to a normal level and remains essentially so throughout the 30 minutes of complete by-pass. Many factors are involved in the pH of the blood aside from the actual process of passing it through the arterializer. Such things as hemorrhage, transfusion, and the arterial pressure are factors causing variations. Prolonged pumping of blood leads eventually to the destruction of blood elements. The first constituent to be affected are the platelets. Following 30 minutes of pumping, there is some diminution in platelets, which may be as high as 50 per cent. We have also found that the eosinophils disappear early in the pumping period. Fragility tests and total blood counts have not been appreciably changed. Free hemoglobin for a 30-minute by-pass is usually not in excess of 100 to 150 mg. per cent.

Given arterialized blood of normal oxygen content, of normal carbon dioxide content, and the acidity adjusted to a normal pH, the perfusion of such blood into the arterial system in such a way as to provide an adequate arterial pressure provides an excellent chance for the opening of the heart and the performance of intracardiac procedures. We believe that not enough stress has been placed upon the arterial pressure. We like to maintain an arterial pressure of 110 to 120 mm. of Hg and, if one can do so using good arterialized blood, it seems unlikely that much serious harm could come to the body, especially during a short period of total by-pass. Our experiments are only for a 30-minute by-pass. We believe this time is sufficient for most intracardiac procedures under vision. We have been able to do a total by-pass in the dog with the right ventricle open for 30 minutes with a recovery rate of 75 per cent.

SUMMARY

A means of arterializing the blood doing a total by-pass is presented. The basic principle is the passing of oxygen and carbon dioxide through a metallic plate with holes of 10 microns in diameter. This produces tiny bubbles which come in contact with the venous blood by a swirling action. Instead of using 100 per cent oxygen, which removes excess carbon dioxide, we use 98 per cent oxygen and 2 per cent carbon dioxide. The addition of 2 per cent carbon dioxide to the oxygen keeps the carbon dioxide at essentially a normal level, and, therefore, the pH is not excessively altered.

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PULMONARY VENTILATION DURING OPEN THORACOTOMY

INFLATION AND DEFLATION TIME RATIOS AND PRESSURES

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RESPIRATORY acidosis is a common occurrence in operative procedures.[1-5] The difficulty in achieving adequate pulmonary ventilation is increased when the thoracic cavity is opened.[2,6,7] Manual or mechanical compression of the breathing bag providing intermittent positive pressure has been used to improve ventilation during operation. A previous report from this laboratory[7] indicated that intermittent positive and negative pressure ventilation was more effective in preventing respiratory acidosis than either of the above methods.

The present report is a further study of intermittent positive and negative pressure ventilation. It is chiefly concerned with the effect upon pulmonary ventilation of the relative duration of inflation and deflation and of the pressures employed. Twenty patients were studied during twenty-one operations. All operations involved an open thoracotomy. The following measurements were made: the pH and carbon dioxide content of arterial blood, the concentration of carbon dioxide in the inspired and expired gas, and the pulmonary ventilation

METHODS

gas flow meter* was placed in the expiratory tubing. This meter has a flow rate capacity of 2.4 to 70 L. per minute with a resistance of less than 0.5 cm. of water at the higher flow rate.

Arterial blood samples were obtained through a Cournand needle in the radial or brachial artery. Specimens were collected in oiled syringes containing a small quantity of heparin and a drop of mercury to aid in mixing the blood.

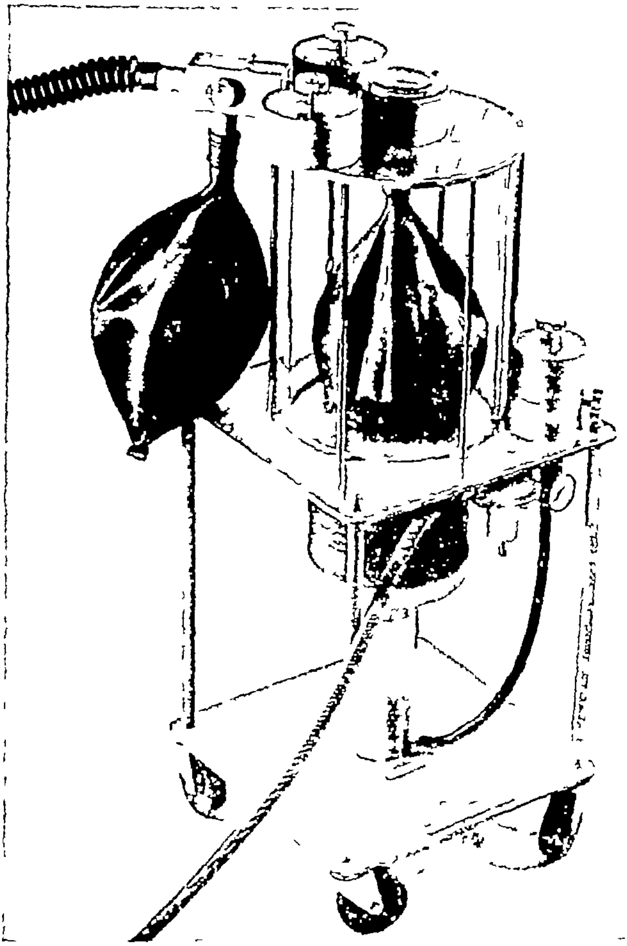

Fig. 1.—Photograph of the ventilator employed. The respiratory tubing is attached to place of the rebreathing bag which is reattached to the ventilator (left of photograph). A switch at the top of the ventilator permits unassisted or manually assisted ventilation with the bag outside, intermittent positive and negative ventilation with the bag inside the cylinder. The latter bag is alternately compressed and expanded by the action of the bellows beneath the cylinder.

Determinations of pH were made promptly after the withdrawal of the blood, using a Cambridge glass electrode pH meter calibrated with standard buffer solution before each determination. Duplicate determinations were made on each specimen and checks to 0.02 pH unit were required. The carbon dioxide

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*American Meter Co., Albany, N. Y.

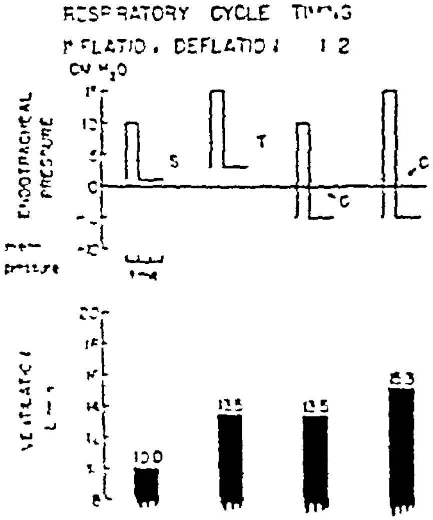
graphs, the recorded pulmonary ventilation is that which was actually measured. The figures have not been corrected for temperature and pressure, nor have they been related to the body surface area. The figures for pulmonary ventilation, therefore, may be compared with one another in the same patient, but are not comparable with the measured ventilation of other patients with different surface areas. With a constant inflation-deflation pressure difference and avoidance of collapse or overexpansion of the lung, the best ventilation was obtained when inflation and deflation were of equal duration (Table I). However, adequate pulmonary ventilation could be provided with an inflation to deflation time ratio of 2:1 (Cases 4 [b], 19, and 20), but it was difficult to provide adequate ventilation during an open thoracotomy with a time ratio of 1:2 (Cases 18, 19 and 20).

Table II lists measurements of pulmonary ventilation with different pressure spans during a constant time ratio of inflation to deflation. Nine patients were studied. In each case the pulmonary ventilation varied directly with the difference in pressure between inflation and deflation provided the lung was neither overexpanded nor collapsed.

TABLE II

CASE NUMBER	RELATIVE DURATION INFLATION: DEFLATION	PRESSURE		PRESSURE DIFFERENCE cm H_2O	VENTILATION L./MIN
		INFLATION cm H_2O	DEFLATION cm H_2O		
3	2:1	+8	-8	16	11.9
		+14	-8	22	15.0
		+16	-10	26	16.8
4 (a)	2:1	+10	-5	15	10.6
		+10	-8	18	12.9
		+10	-10	20	13.7
		+15	-10	25	15.8
5	2:1	+10	-10	20	11.7
		+15	-10	25	16.2
6	2:1	+15	-6	21	12.6
		+15	-8	23	13.9
		+15	-10	25	14.3
		+17	-8	25	14.4
9	1:1	+17	-7	24	20.0
		+19	-5	24	21.0
		+19	-7	26	24.0
11	1:1	+18	-5	23	16.5
		+18	-10	28	19.0
13	1:1	+15	-10	25	18.5
		+15	-12	27	19.5
		+17	-15	32	21.5
19	1:1	+10	+1	9	11.3
		+15	+2	13	15.6
		+15	-5	20	18.6
20	1:1	+15	+4	11	15.6
		+15	-5	20	21.5

Figs. 2, 3, and 4 are graphic illustrations of the studies made on 1 patient (Case 19) (Tables I and II). This man had pulmonary tuberculosis confined to the right upper lobe. The remainder of the lung was normal. Diagrammatic representations of the pressures and the timing of one respiratory cycle are shown in the upper half of each figure. The horizontal dotted line indicates the mean pressure during the respiratory cycle. The condition of the lung as [illegible] is indicated by the capital letters adjacent to the horizontal [illegible] line. When the mean pressure was in the neighborhood of 5 cm. of H$_2$O the lung appeared to the surgeon to be properly expanded and yet it was soft [illegible] could be moved easily. This is indicated by the letter S. The letter T [illegible] overexpanded lung and the surgeon complained of the difficulty [illegible] good exposure of the operative field. Every time such a complaint [illegible] the mean pressure was 7 cm. or above. When the mean pressure fell [illegible] the surgeon observed that although the lung expanded partially



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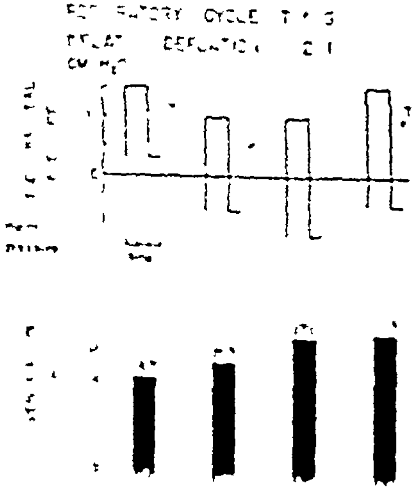
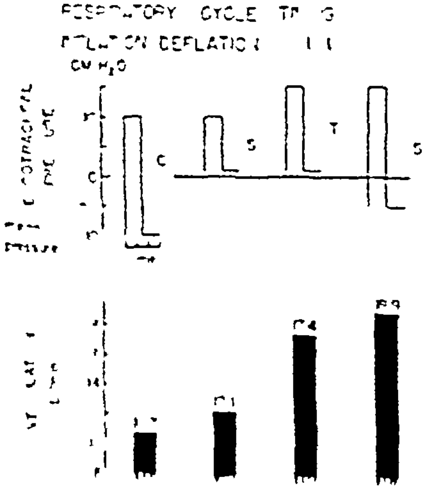


TABLE III

CASE NUMBER	DIAGNOSIS	OPERATION	DURATION OF OPERATION	THE pH AND pCO_2 OF ARTERIAL BLOOD					
				AFTER ENDOTRACHEAL INTUBATION		AVERAGE DURING OPERATION WITH VENTILATOR		END OF OPERATION SPONTANEOUS RESPIRATION	
				pH	pCO_2	pH	pCO_2	pH	pCO_2
1	Bronchogenic carcinoma	Lobectomy with partial excision of chest wall	4°33′			7.42	28.8	7.30	42.0
2	Bronchogenic carcinoma	Exploratory thoracotomy	2°20′	7.25		7.33	44.0	7.36	40.0
3	Pulmonary tuberculosis	Lobectomy	6°33′	7.28	61.0	7.37	48.1	7.33	47.0
4 (a)	Bronchiectasis	Lobectomy and segmental resection	4°40′	7.20	77.0	7.22	64.8	7.23	61.6
(b)	Bronchopleural fistula	Closure	4°37′			7.37	32.8	7.31	44.5
5	Bronchogenic carcinoma	Pneumonectomy	3°42′	7.26	63.0	7.36	42.8		
6	Pulmonary tuberculosis	Lobectomy	3°55′			7.38	33.0	7.34	41.0
7	Intrathoracic neurofibroma	Excision	2°36′			7.31	39.8	7.32	37.6
8	Myasthenia gravis	Thymectomy	2°30′	7.32	50.8	7.45	28.4	7.15	26.8
9	Neurofibroma of diaphragm	Excision	2°50′	7.32	52.0	7.42	34.5	7.41	38.5
10	Bronchiectasis	Lobectomy and segmental resection	3°55′	7.24	72.0	7.36	41.0	7.32	37.5
11	Bronchogenic carcinoma	Pneumonectomy	4°38′	7.29	41.6	7.34	34.7	7.35	36.8
12	Anthracosilicotic granuloma	Exploratory thoracotomy	3°28′	7.32	50.0	7.30	45.5	7.24	41.0
13	Pulmonary tuberculosis	Lobectomy	3°50′	7.17	82.0	7.29	59.3	7.38	51.0
14	Perinephric abscess with pleural effusion	Exploratory thoracotomy drainage of abscess	3°40′	7.40	40.0	7.49	30.6	7.44	35.0
15	Bronchogenic carcinoma	Exploratory thoracotomy	2°10′	7.27	52.0			7.34	39.5
16	Tuberculoma	Wedge resection	1°45′	7.34	35.5	7.32	37.6	7.29	41.3
17	Bronchogenic carcinoma	Exploratory thoracotomy	2°10′	7.29	55.0	7.33	43.1	7.40	41.0
18	Atrial septal defect	Closure	4°30′						
19	Pulmonary tuberculosis	Lobectomy	3°11′						
20	Bronchiectasis	Lobectomy and lingulectomy	3°40′						

during inflation it appeared to be collapsed during the remainder of the respiratory cycle. The bar graphs at the bottom of the figures indicate the measured pulmonary ventilation in liters per minute using the inflation to deflation ratios indicated at the top of the figures and the pressures shown diagrammatically [illegible].

As might be expected with an open thoracotomy, it was difficult to produce as much pulmonary ventilation when the deflation period was longer than the period of inflation (Fig. 2). With an inflation pressure not higher than 15 cm. H₂O the best ventilation was 15.3 L. per minute. When the inflation period was longer than the deflation period the pulmonary ventilation was better (Fig. 3). Without producing a tense overexpanded lung the best ventilation was 17.1 L. per minute. The greatest pulmonary ventilation, 18.9 L. per minute, was achieved when inflation and deflation were of equal length (Fig. 4). This ventilation of approximately 19 L. per minute was achieved with an inflating pressure no greater than 15 cm. H₂O and with a normally expanded, soft and retractable lung.



and in 6 patients was markedly elevated at the time of intubation With the use of the ventilator, the arterial pCO_2 fell rapidly to near normal levels with the exception of 2 cases (*A* and *B*, Fig 5)

In Case 4 (a) (*A* on Fig 5) studied early in our experience, the elevated pCO_2 was not recognized During a subsequent procedure, Case 4 (b) (Table III), the pCO_2 level was easily maintained below 40 mm Hg Case 13 (*B* on Fig 5) was a short, stocky individual with severe pulmonary emphysema He was markedly acidotic when the endotracheal tube was inserted pH 7 17, pCO_2 82 0 mm Hg Throughout the operation, the pulmonary ventilation was 18 to 21 L per minute The pCO_2 of the arterial blood gradually fell but did not reach normal values The greatest ventilation was obtained in this patient with a mean endotracheal pressure of +1 A high negative pressure was necessary to deflate the lungs (Table II)

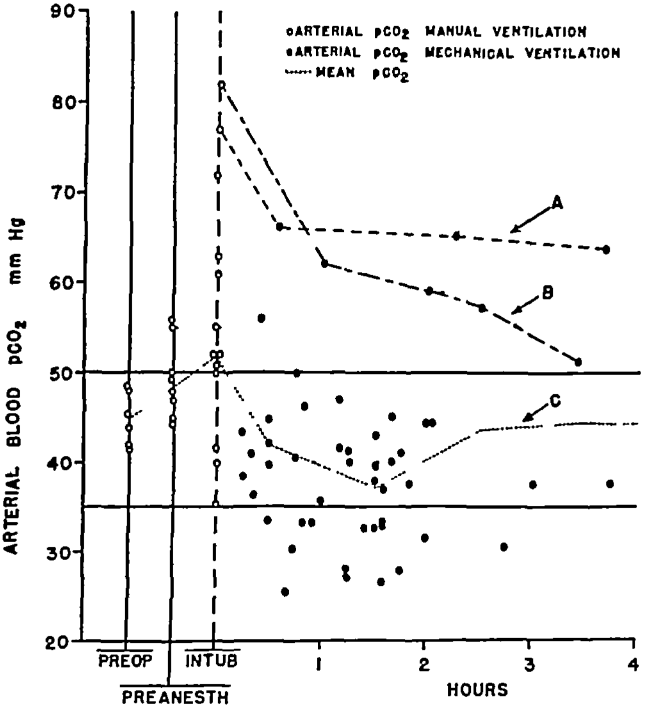
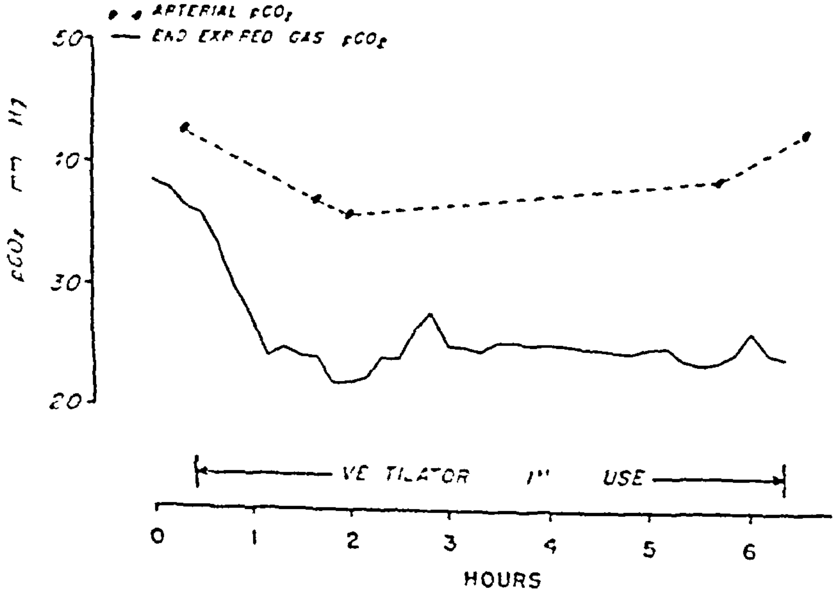


Fig 5—The pCO_2 of arterial blood during eighteen operations In 6 patients this value was determined the day before the operation (*PRE-OP*) In 8 patients the pCO was measured just before the induction of anesthesia (*PRE-ANESTH*) In 13 patients the pCO_2 was measured immediately following endotracheal intubation (*INTUB*) For explanation of *A* and *B*, Cases 4 (a) and 13 see text. *C* is the mean of all the points in the graph The heavy horizontal lines indicate the upper and the lower limits of normal values

The value of intermittent positive and negative pressure anesthesia is well illustrated in Case 3 A lobectomy for pulmonary tuberculosis was attempted twice, employing intermittent positive pressure anesthesia On both occasions the operation was not begun because of a rapid pulse and a falling blood pressure following induction of anesthesia When positive and negative pressure was used, satisfactory ventilation was achieved for over six hours (Fig 6) In this gas, the pCO_2 of expired gas was measured by the Liston Becker gas analyzer. The failure of the analyzer to record values of carbon dioxide equal to the levels in the arterial blood was probably due to technical factors which possibly can be eliminated. Nevertheless the pCO_2 of the expired gas roughly paralleled changes in the pCO_2 of the arterial blood and provided a continuous indication that the pulmonary ventilation was adequate.

Another illustration of the value of continuous analysis of the expired gas is shown in Fig. 7 (Case 1). The per cent carbon dioxide in both the expired (top of tracing) and the inspired gas (bottom of tracing) is shown. Positive



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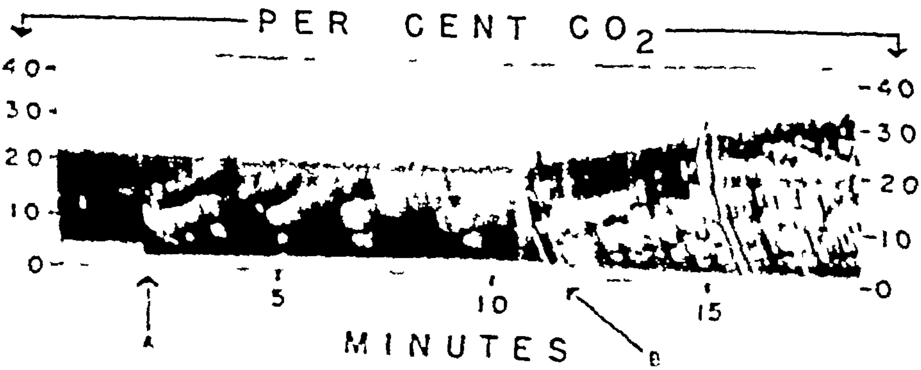

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and negative pressure ventilation was used until point *B* At point *A*, the soda lime canister was changed resulting in an immediate reduction in the per cent of inspired carbon dioxide At *B*, the ventilation was changed to intermittent positive pressure at the same respiratory rate The progressive rise in the per cent carbon dioxide of the expired gas is evident A tracing such as this illustrates the value of continuous analysis of the expired gas in detecting poor function of the soda lime canister and the onset of respiratory acidosis As in Fig 6, the per cent carbon dioxide of expired gas, in this tracing, was below that of alveolar gas as shown by determination of the pCO_2 of arterial blood Nevertheless the tracing reflected directional changes in the pCO_2 of arterial blood.

SUMMARY

1 With an open thoracotomy, the degree of expansion of the lung is a function of the mean endotracheal pressure within the obvious limits of collapse or overdistention In the absence of generalized pulmonary disease, a mean endotracheal pressure of +4 to +6 cm H_2O resulted in normal expansion of the lungs With emphysema, lower mean pressures were required to avoid over expansion of the lungs

2 Avoiding collapse or distention of the lungs, with a respiratory rate of 20 per minute, and with a constant difference in pressure between inflation and deflation, the greatest pulmonary ventilation was achieved when the duration of inflation was equal to the duration of deflation

3 Avoiding collapse or distention of the lung, with a respiratory rate of 20 per minute, and with equal duration of inflation and deflation, the pulmonary ventilation varied directly with the difference in pressure between inflation and deflation

4 Greater pulmonary ventilation at a lower mean pressure can be achieved with the use of negative pressure during deflation Negative pressure is also of great value in assisting the deflation of emphysematous lungs

5 The use of positive and negative pressure ventilation resulted in normal or reduced levels of pCO_2 of arterial blood in 16 of 18 cases of open thoracotomy

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Original Communications

LOBAR VENTILATION AND OXYGEN UPTAKE IN MAN

Influence of Body Position

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As EARLY as the close of the nineteenth century it was suggested that the blood flow in different parts of the lungs varies to a certain extent with the position of the body In conjunction the theory was advanced that anemia in the apices of the lungs when the posture is erect was the cause of "apical tuberculosis " This led to the introduction by different investigators of postural treatment in pulmonary tuberculosis Bjure and Laurell[1] (1927) were of the opinion that they could demonstrate roentgenologically that the vascular flow in the uppermost portion of the lung was less in the standing than in the recumbent position This condition they interpreted as an orthostatic arterial anemia Bronchospirometry with the patient in the lateral recumbent position, which was first performed by Bjorkman[2] (1934) and subsequently repeated by numerous investigators, shows rather unequivocally that the lower lung increases its oxygen uptake at the expense of the upper, notwithstanding the fact that the ventilation often retains the same relation as in the supine position Bjorkman suggests that "it is plausible that this is caused by increased perfusion in the lower lung and decreased in the upper resulting from the body position " Since cardiac catheterization has opened the possibility for measurement of the pressure in the pulmonary artery, interest has been renewed in the question of the significance of the orthostatic pressure to the pulmonary circulation Taking as the point of departure, the normal pressure in the pulmonary artery and the estimated height of a column of fluid from the right ventricle to the apex of the lung, Dock[3] (1946) calculated that the apex in adults has little or no blood flow in the erect posture Lagerlof, Eliasch, Werko, and Berglund[4] (1951) *reached similar conclusions* Through comparative analysis of the alveolar air in different parts of the lung in man in the upright and recumbent positions Martin, Cline, and Marshall[5] *(1953) arrived at results that may be interpreted as an effect of* decreased pulmonary circulation in the right upper lobe in the upright posture They showed that in this position the partial pressure of the oxygen was higher *and that of the carbon dioxide* was lower in the upper lobe than in the lower In the recumbent position the relation between the gases in the two lobes was reversed They write "Whether this pattern is a result of ventilation and/or perfusion changes cannot be stated " Sadoul and Rahn[6] (1954) made similar observations on anesthetized dogs

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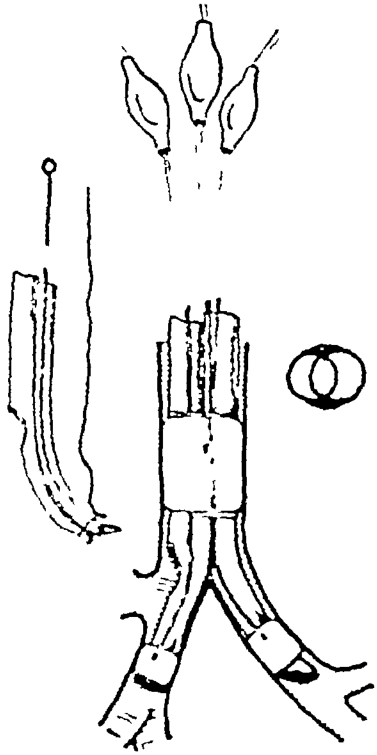
The purpose of the present study has been to determine spirometrically if and to what extent any shift occurs in the blood flow between the two regions of the lesser circulation above and below the pulmonary trunk when a man's position is changed from recumbent to erect. Anatomically the right lung is well adapted to such a dissociated spirometric investigation since, in the erect subject, the upper lobe is almost entirely above the level of the pulmonary trunk and the two basal lobes are below. The construction of a suitable catheter has enabled us to measure the ventilation and oxygen uptake simultaneously in the upper and the two basal lobes of the right lung.



[illegible]

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cal examination showed no indications of cardiac disease. On the basis of these observations, we feel justified in assuming that normal pressure existed in the lesser circulation. Patients with a wide laryngeal passage were selected, and in all cases the examination could be performed under correct technical conditions.

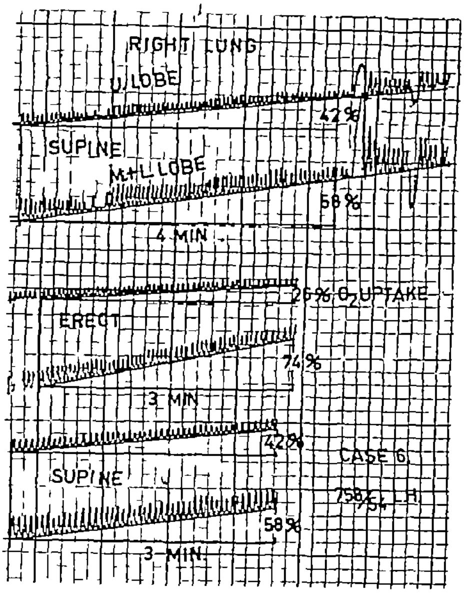

Fig. 2.—Spirometric tracings of different lobes of the right lung in supine and erect positions (Case 6).

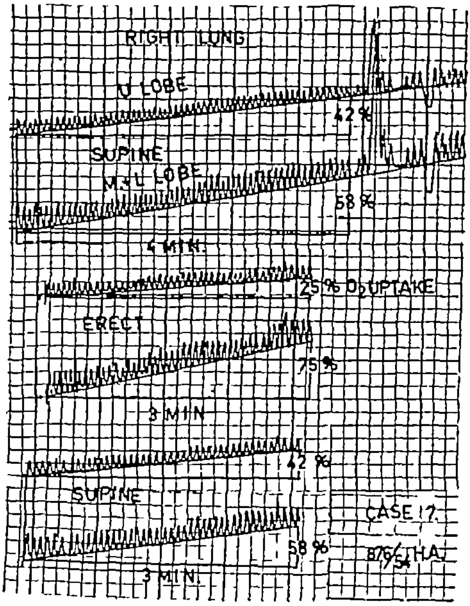

Fig. 3.—Spirometric tracings of different lobes of the right lung in supine and erect positions (Case 7).

METHODS

The patients received premedication consisting of 2 cg Pantopon, 10 cg luminal, and 1 mg atropine administered subcutaneously 30 to 45 minutes prior to the topical anesthesia of the pharynx, larynx, and trachea with a small amount of 2 per cent tetracaine hydrochloride solution. The flexible catheter (Fig. 1) was passed under mirror guidance over a curved stylet through the larynx and down into the trachea. To facilitate the entrance the branches of the catheter were tied together with a slip knot. When the catheter was in the trachea, the stylet was removed and the knot was untied. The patient was placed supine on a table, and the correct position of the catheter was controlled fluoroscopically. After inflation of the cuffs, the channel to the right upper lobe was connected to one recording spirometer and the channel to the middle and lower lobes to another, both filled with oxygen. This twin spirometer is that originally described by Bjorkman (1934). The carbon dioxide in each circuit was absorbed by potassium hydroxide. In these experiments the ventilation of the left lung was not recorded. This lung was breathing ambient air, and the large tube in its main bronchus guaranteed free passage. The resistance to air flow in the catheter was investigated, and for the minute ventilation in question it never exceeded 0.7

[illegible] ater. Before the recordings it was ascertained that the passage in the channels was free by aspiration of any secretion that might be present. In none of the experiments did the patients exhibit any signs of dyspnoea. After an observation period of several minutes during which the patient was allowed to reach a steady state, the oxygen uptake and ventilation were recorded during four minutes, first with the patient in the supine position. Then after the table was tipped to place the patient in the erect position and similar recordings were taken during three minutes. As may be seen from Figs 2 and [illegible] this period should be quite sufficient to give an accurate measure of the oxygen uptake. In several cases the patient was then tipped back into the supine position and a third set of recordings made to verify the accuracy of the first. The interval between recordings was about five minutes.

In order to ascertain that the catheter had remained in the correct position during the examination and that the passage to the respective lobe bronchi had been free, a bronchographic examination was carried out immediately after the recordings were finished. With a small quantity of contrast medium

tracing does not instantly return to the respiratory mid-position after a maximum inspiration or expiration. There is a risk, however, that such a maximum respiratory movement may displace the position of the catheter.

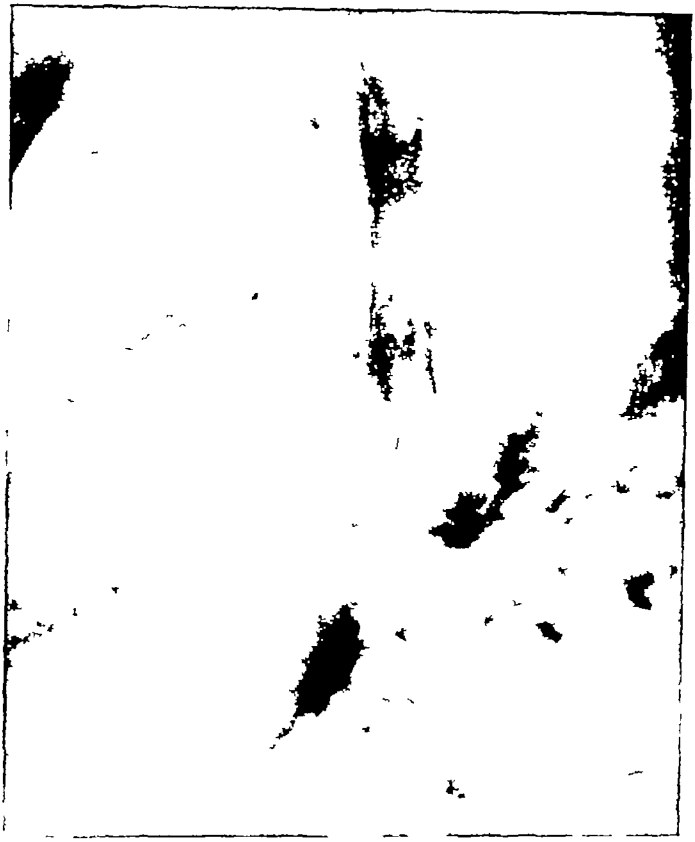

Fig. 5.—After roentgen examination of the upper lobe (Fig. 4) the middle and lower lobes were similarly examined (lateral view).

RESULTS AND DISCUSSION

As is evident from Table I, the minute ventilation changed somewhat for the entire lung, but without any definite tendency, in the transition from supine to erect position. Under the same conditions the percentile share of the upper lobe in the ventilation showed an average decrease that was inappreciable ($m = 1.6$) but almost significant ($P < 0.05$).

Table I. Ventilation (Liters per Minute) of Right Lung

CASE	AGE IN YEARS	ENTIRE LUNG		UPPER LOBE		MIDDLE LOBE + LOWER LOBE		UPPER LOBE EXPRESSED AS PERCENTAGE OF ENTIRE LUNG		
		SUPINE	ERECT	SUPINE	ERECT	SUPINE	ERECT	SUPINE	ERECT	DIFFERENCE
1 K. H.	25	7.7	8.4	2.6	2.8	5.1	5.6	34	33	-1
2 S. J.	35	10.0	9.1	4.4	3.6	5.6	5.5	44	40	-4
3 A. B.	28	5.9	7.4	2.5	2.9	3.5	4.5	42	40	-2
4 L. N.	37	9.1	9.0	3.6	3.6	5.5	5.4	40	40	0
5 B. K.	21	4.7	5.5	1.9	2.2	2.8	3.3	40	40	0
6 L. H.	23	3.8	3.4	1.4	1.2	2.4	2.2	37	35	-2
7 H. A.	24	4.6	4.9	1.8	1.8	2.8	3.0	39	37	-2

infected intravenously with human tubercle bacilli results in an extensive caseous form of the disease in the lung on the side of the anastomosis

The figures given here as a measure of the decreased oxygen uptake in the upper lobe must, of course, be regarded as mean values for the different parts of the lobe It is therefore justifiable to assume that the venous blood flow in the apical parts is even less and perhaps, in certain cases, even totally absent It is improbable, however, that the capillaries collapse and that the apex becomes completely empty of blood under these conditions, inasmuch as in experimental block of the venous circulation a flow of blood is very quickly obtained peripheral to the block with arterial blood from anastomoses with the bronchial arteries (Nordenstrom,[8] 1954)

As pointed out previously, when there is a pressure rise in the lesser circulation, the physiologic decrease of the blood flow in the apex in the erect position, which has been demonstrated here, may be expected to be moderated or entirely abolished In the case of pathologically low pressure, this decrease should be more pronounced Typical examples of such pathologic changes in pressure are found in mitral stenosis and in pulmonary stenosis, with increased pressure in the former and decreased in the latter Moreover, it has long been known, and statistically verified by White[9] (1944), that pulmonary tuberculosis occurs less frequently in patients with mitral stenosis and considerably more frequently in those with pulmonary stenosis than in the population as a whole

SUMMARY

The ventilation and oxygen uptake in the upper lobe and the basal lobes of the right lung was spirometrically investigated in 7 male patients A comparative study showed an inconsiderable decrease in the ventilation ($m = 1\ 6$) but an appreciable decrease in the oxygen uptake ($m = 18\ 6$) in the upper lobe with a change from the supine to the erect position

The decreased perfusion in the upper lobe is probably orthostatic in origin and may give rise to increased alveolar oxygen tension

The significance of the changed circulation to the predominantly apical localization of postprimary tuberculosis is discussed

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the elbow The temperature of the water was maintained at 45 to 47° C by adding hot water as needed At the end of the 10-minute period, the hand was withdrawn from the water just enough so that venepuncture could be carried out on the dorsum A 10 ml sample of blood was withdrawn anaerobically by gentle aspiration, using a 20 ml eccentric tip syringe with a No 20 gauge needle The dead space of the syringe and needle was filled with concentrated heparin (100 mg/ml) prior to drawing the blood sample After the blood was drawn, a small amount of mercury was aspirated into the syringe to aid in mixing, the syringe tip was plugged with a toothpick, and the syringe agitated Arterial blood was drawn at the same time from the contralateral brachial artery via a Cournand needle which had been placed in the artery In three subjects a sample of venous blood was drawn within an hour from the same site as the "arterialized" blood, with the patient under similar resting conditions

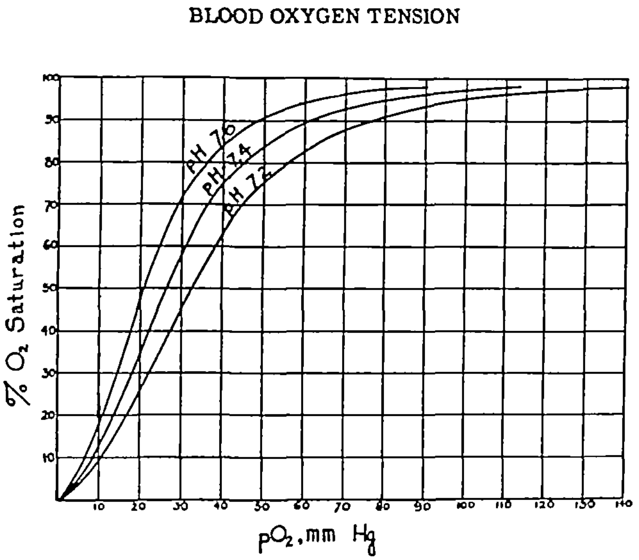

Fig 1 —Oxyhemoglobin dissociation curve constructed from the data of Dill (From J H. Comroe Jr editor Methods in Medical Research Chicago 1950 The Year Book Publishers vol 2 p 163)

All blood samples were drawn without the use of a tourniquet Analysis of blood samples was performed immediately The CO_2 and O_2 tensions were determined with the Scholander blood gas tension apparatus by the method of Filley,[5] utilizing 30-unit Roughton-Scholander syringes All tension determinations were carried out in duplicate, and checked within 6 mm Hg Tensions were expressed as the average of duplicate determinations

Although we have not determined the correction factors for absolute values of the CO_2 and O_2 tensions by tonometry, the same correction factors apply to each pair of arterial and "arterialized" blood determinations and, therefore, the tensions in "arterialized" and arterial blood can be properly compared

RESULTS

Determinations of O2 and CO2 tensions on brachial artery blood and arterialized venous blood drawn simultaneously from the dorsum of the hand were carried out under resting conditions in 14 male patients, some normal and some with pulmonary disease. Similar studies were accomplished on [illegible] additional patients with blood drawn simultaneously from the brachial artery and a forearm or antecubital vein. None of the patients had any local disease which would have interfered with the peripheral vascular response.

Table I lists the CO2 and O2 tensions in the 17 patients.

TABLE I

[illegible]		pCO2 mm Hg			pO2 mm Hg		
	[illegible]	ARTERIALIZED	ARTERIAL	DIFFERENCE	ARTERIAL	ARTERIALIZED	DIFFERENCE
1	[illegible]	[illegible]	[illegible]	0.2	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	0.8	[illegible]	[illegible]	[illegible]
3	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	-3.1	[illegible]	[illegible]	[illegible]
5	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-11.6
9	44	[illegible]	47.8	[illegible]	[illegible]	77.0	-10.7
10	[illegible]	40.1	[illegible]	0.2	[illegible]	[illegible]	[illegible]
11	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	51.0	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table II presents a comparison of the arterialized and arterial blood [illegible] tensions in the group as a whole. The average determined CO2 [illegible] arterialized blood was 1.1 mm higher and the average determined O2 [illegible] was 7.2 mm lower than in arterial blood. The difference

TABLE II

TABLE III

	pO MM Hg	pCO MM Hg
Number of patients	14	14
Mean tension (avg.) in "arterialized" blood	66.6	42.7
Mean tension (avg.) in arterial blood	72.1	41.7
Difference of the means	-5.5	+1.0
Mean (avg.) of the differences (without regard to sign)	6.3	2.95
Extreme differences ("arterialized" minus arterial)	-11.6 to +3.5	-4.4 to +11.6

(Table III). The difference between "arterialized" and venous blood drawn from the same area at different times, but with the patient under the same resting conditions, gives an approximate indication of the extent of the change in venous blood produced by "arterialization" (Table IV).

TABLE IV

CASE NO.	pCO$_2$			pO		
	VENOUS	"ARTERIALIZED"	ARTERIAL	VENOUS	"ARTERIALIZED"	ARTERIAL
14	59.6	44.9	46.8	26.2	51.0	59.8
16	47.9	45.2	46.6	45.0	78.1	80.3
17	46.4	34.4	34.6	40.9	74.4	72.8

DISCUSSION

In patients under resting conditions, venous blood "arterialized" by the method of Goldschmidt and Light is equivalent to arterial blood in CO$_2$ tension. While "arterialized" blood is not identical to arterial blood in its O$_2$ tension, the tension does approach that of arterial blood to a reasonable degree. We feel that the degree of approximation is such that "arterialized" blood may possibly be used instead of arterial blood in many tests that involve the determination of arterial CO$_2$ and O$_2$ tensions. Experiments are now in progress in this laboratory to determine the validity of this contention.

On the basis of these experiments, and those of Goldschmidt and Light, it seems advisable to confine the sampling of "arterialized" blood to the veins on the dorsum of the hand.

SUMMARY

Blood gas tension studies on 17 patients, at rest, demonstrate that "arterialized" venous blood approximates arterial blood in its CO$_2$ and O$_2$ tension levels.

We wish to acknowledge the advice and technical assistance of Mrs. Dorothy H. Burke, Biochemist, Surgical Research Laboratory, Veterans Administration Hospital, Providence, R. I.

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Group 1 represents the valves in which there is a small regurgitant jet in association with mitral stenosis and a small, tight, perhaps calcified orifice, 1 cm or less in length As there has been complete fusion of the commissures and therefore no loss of cusp substance, after commissurotomy the released cusps function apparently normally This regurgitation is of little significance by itself

Group 2 represents the valves in which there is a moderately powerful regurgitant stream occurring with an orifice of 1 5 to 2 5 cm in length The causative rheumatic carditis may have fused the anterior commissure, but by fibrosis and calcification held the posterior commissure widely open Alternatively, the aortic or more usually the posterior cusp may be shortened, or again they may be tethered down by shortening of the musculotendinous mechanism to form a cone-shaped mitral opening

Group 3 represents the valves in which there is a powerful current through a large mitral orifice at least 3 to 4 cm in diameter In this lesion there is no stenosis, but rather a "dehiscence of the annulus" (Black[2]), where the regurgitation is due solely to failure in normal valvular approximation

As yet it is not possible to get reliable figures on the relative frequency of Groups 2 and 3 In a recent clinical study of 30 patients with mitral incompetence, Brigden and Leatham[3] studied 9 necropsies The mitral ring was of normal size in 1 case only, and was dilated in the remainder All showed thickening and deformity of the valve cusps with calcification in 2 cases The chordae tendineae were thickened in 6 cases and in 2 of these a chorda was ruptured

METHODS OF SURGICAL CORRECTION

In Group 1, the small jet associated with a tight mitral stenosis is an incidental finding The treatment is correction of the mitral stenosis

Groups 2 and 3 claim closer study To date none of the published methods of surgical correction has been completely satisfactory in itself

Bailey,[4] who pioneered its surgical treatment, pointed out in 1951 the relative dearth of valvular tissue in mitral insufficiency, and emphasized that surgical treatment must logically be directed along the lines of either supplying additional valve substance to bridge the aperture, or else of reducing the size of the aperture so that the available valve tissue will become adequate in amount

To this end he at first devised two operative procedures, one in which a pedicled pericardial graft was placed across the left ventricle to *tamponade the mitral orifice from below,* and the other in which it was hoped *to narrow the valve orifice* by sewing the chordae tendineae with purse string sutures

Indifferent results on clinical trial, however, made him devise a third procedure[5] in which there was a direct attack on the diseased valve cusps, the attack taking one of two forms He assumed there was predominantly one type of defect with widely separated cusps posteriorly In this procedure the affected cusps are either suspended singly to the ventricular wall, or else the

correcting mitral insufficiency, especially in the Group 3 pattern, in which a widely dilated valve orifice was present If such a suture could be passed in human beings then the degree of tightening required to abolish the insufficiency could be gauged by atrial exploration Further, in the Group 2 cases, if there was also an associated stenosis of one commissure, then commissurotomy could be carried out and the tightening continued to accommodate the insufficiency

Experiments on sheep were therefore commenced on Sept 21, 1953, and the preliminary results reported[10]

METHOD I

The left side of the heart was exposed through the bed of the resected left fifth rib As it was not possible to produce an insufficiency similar to that occurring with mitral rheumatic disease, it was decided to pass the suture and observe its effect on the normal heart, by examining the heart three months after operation, and assessing the narrowing of the ring

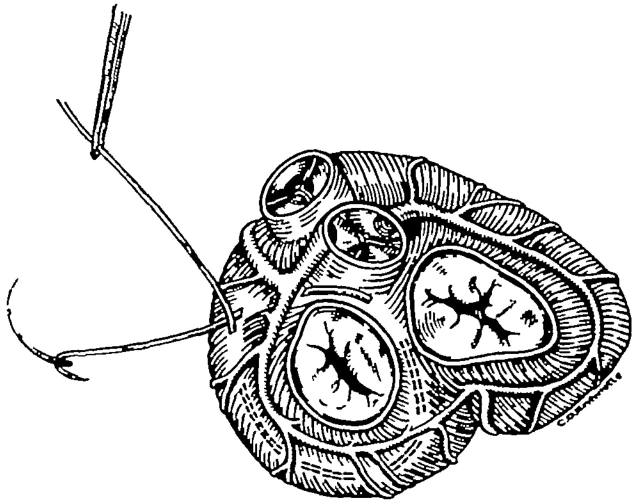


Fig 1 —Method I The circular suture lay below the coronary artery passing under its branches

The first step was to dissect free the main left coronary artery as it arose from the aorta, to define its course in the transverse sinus, and to isolate the origin of its two major divisions When these had been isolated, a double floss-silk suture was inserted on a No 8 round-bodied needle Floss silk is strong, has been well tried for repair of direct inguinal hernia (Maingot[11]) and, when lubricated with sterile paraffin and inserted doubled, is sufficiently bulky to seal any needle hole

In the first series of experiments, the suture commenced on the left side of the ventricle just below the main division of the left coronary artery, and, by under-running all obvious branches, continued to the inferior interventricular sulcus where left and right coronary arteries anastomose (Fig 1) At this point, the suture was passed through the heart along the interven-

Fig 2

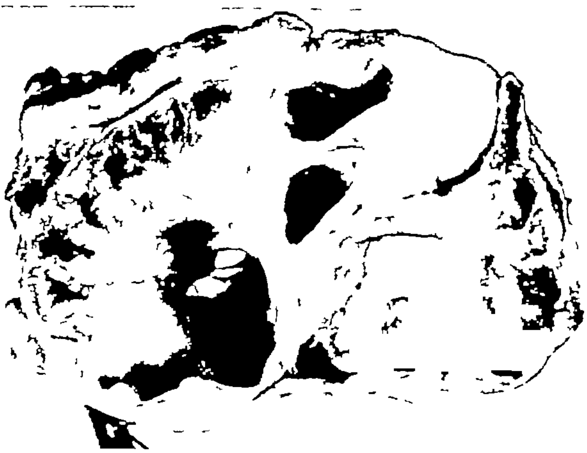


Fig 3

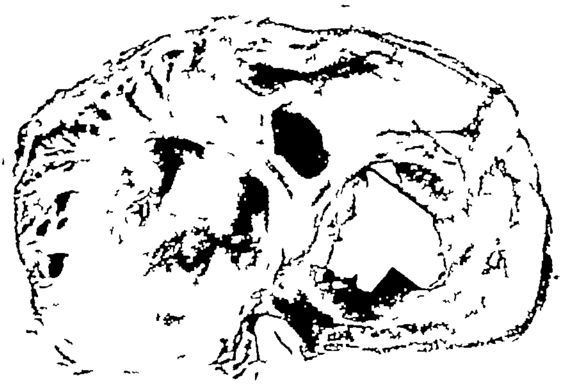


Fig 4

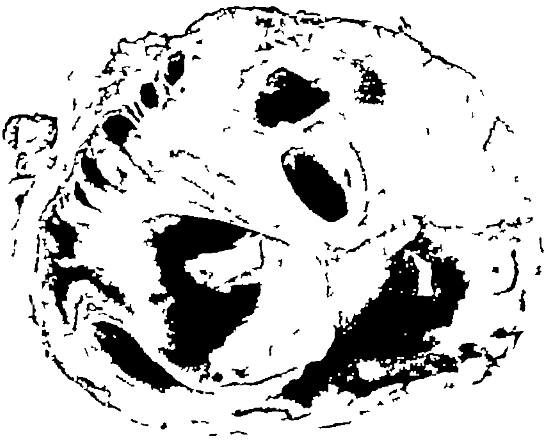


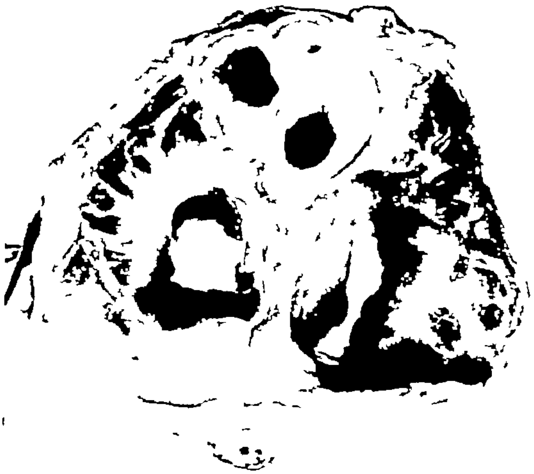
Fig 2 —Initial attempt. The transcardiac suture crossed to the left of the mitral orifice

Fig 3 —Second attempt. With the suture over the mitral orifice fibrin forming on it caused mitral obstruction within 2 weeks

Fig 4 —Third attempt. Suture lying just to left of interventricular septum

determine the long-term result The heart showed a firm, narrowed left A-V ring with normal functioning valve cusps In several the diameter of the ring had been reduced to half its normal width (Figs 6 and 7)

Fig 6



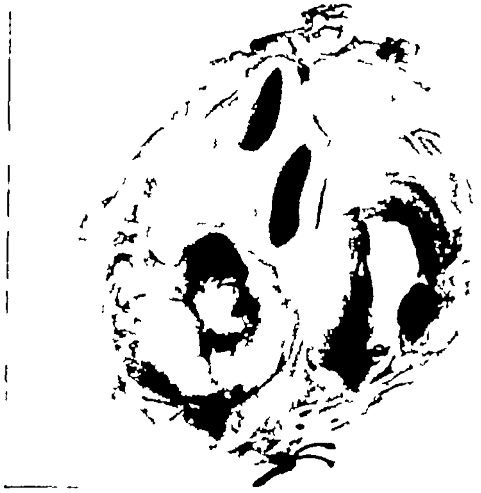


Fig 7

Fig 6—Method II Circular constriction of left A-V ring without disturbing cusp function

Fig 7—Result similar to Fig 6

The atria were cut away to show the upper surface of the mitral and tricuspid orifices Depending on the degree of tightening of the circular suture before ligation, so the diameter of the left A-V ring varied, but in several it was reduced to almost half its normal diameter It was very firm and, as histological examination confirmed, more fibrous than normal (Figs 8, 9, and 10) The valve cusps and chordae tendineae had continued to function normally

COMMENT

These results showed therefore (1) that the left A-V ring can be effectively narrowed by passing a floss-silk suture around it and tightening the suture, (2) that the mitral valve cusps continue to function adequately under such circumstances, and (3) that the fibrous A-V ring is considerably thickened by the presence of this suture

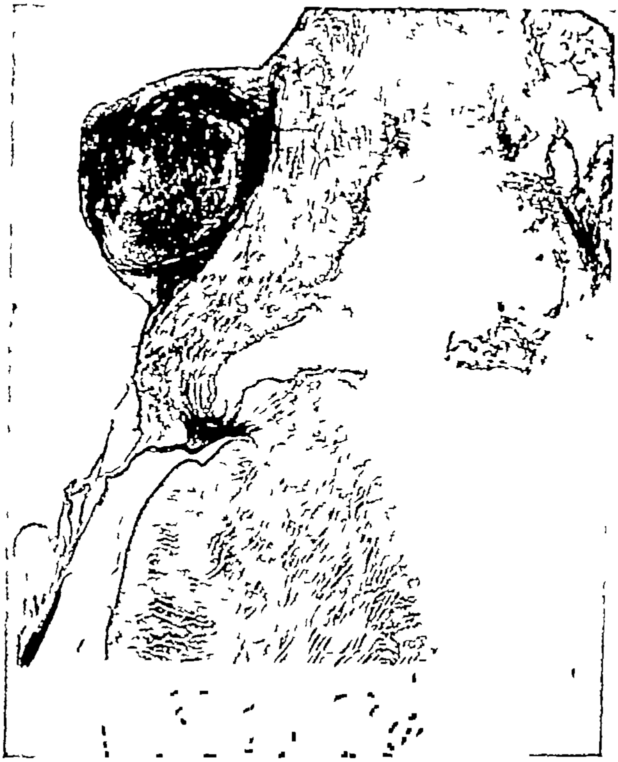


Fig 10—Further example similar to Fig 9

SUMMARY AND CONCLUSIONS

The fibrous ring supporting the mitral valve can be effectively narrowed by passing a double floss silk circular suture around it In the initial 18 experiments, where the suture lay below the left coronary artery, although 11 animals recovered from operation, 3 died from acute coronary occlusion In 9 subsequent experiments, where the suture lay above the left coronary artery, all animals recovered The resulting narrowing and thickening of the A-V ring did not interfere with the action of the mitral valve cusps and chordae tendineae

It is concluded that this method may well prove to have a real place in the surgical correction of mitral insufficiency, especially in patients with a widely dilated mitral valve ring Cardiotomy would be the first step to assess the pathologic type of mitral insufficiency Thereafter, the circular suture would be inserted, and the degree of tightening judged by intracardiac palpation

BLOODY PLEURAL EFFUSION CAUSED BY A BRONCHOGENIC CYST

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George W B Starkey, M D ***
Boston, Mass

THE common clinical teaching that a bloody pleural effusion is secondary to carcinoma or tuberculosis is usually valid Recently, however, we have had under our care an unusual case of bloody pleural effusion secondary to a bronchogenic cyst, which forms the basis of this report

CASE REPORT

B J (B C H, No 1505272), a 20 year old single white woman, entered the Boston City Hospital for the first time on March 30, 1954, with the chief complaint of chest pain and shortness of breath of four days' duration. She stated that, one month prior to admission, she had developed a cold with a cough productive of brownish black sputum, which continued up to the time of admission She was able to continue work as a sales clerk in a department store, although she did not feel well Her appetite remained good There was no weight loss There had been occasional mild night sweats, but the patient felt that these usually followed the taking of aspirin

Four days prior to admission, while at work she was suddenly seized with a substernal pain described as sharp and stabbing and which was aggravated by breathing and coughing After a short rest, she was somewhat relieved and went back to work It was noted that with the onset of sharp pain, there was associated shortness of breath and this had gradually increased until the time of admission to the hospital The location of the pain changed gradually and was felt most acutely in the left upper anterior chest, remaining pleuritic in nature There was no history of contact with tuberculosis She had had pneumonia at the age of 6, at which time her mother stated that she was "run down and thin " Questioning revealed that she smoked one package of cigarettes per day Leg cramps had been noted occasionally, but without calf tenderness There was no history of chills and fever, or previous heart disease

Physical examination revealed a fairly well developed, well nourished, young white woman, showing marked dyspnea There was mild convergent strabismus of the right eye The skin of the face revealed extensive acne The teeth were markedly carious Examination of the chest revealed signs of pleural effusion up to the apex on the left with marked mediastinal and tracheal shift to the right The heart sounds were heard best to the right of the sternum The remainder of the physical examination was essentially negative

Laboratory —The urinalysis was negative The hematocrit was 34 per cent The corrected sedimentation rate was 22 mm per hour The white blood count was 13 700 cells, showing 13 per cent monocytes, 12 per cent lymphocytes and 75 per cent polymorphonuclear leukocytes Of the latter, 50 per cent were young forms X rays revealed a homogeneous density of the entire left chest (Fig 1) A chest tap produced 1,100 c c of bloody fluid

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was bounded below by the diaphragm, medially by the posterior mediastinum, and superiorly by the inferior surface of the lung, which it pushed upward The lung was completely atelectatic The cystic structure was completely separated from the lung and diaphragm and was found to be attached by a 2 cm stalk to the lower esophageal wall This stalk appeared to be composed of muscle fibers, vessels, and nerves Rupture of the cyst during its removal showed it to contain approximately 700 c c of greenish gray, mucoid material The palpating finger within the cyst was easily able to feel the Levin tube within the esophagus, with only mucosa intervening between the finger and the tube The stalk was then amputated and the defect in the esophageal musculature was closed with interrupted silk sutures Decortication of all visceral and parietal surfaces was then carefully done and the lung expanded It was noted that even with pressure, the expanded lung would not completely fill the hemithorax Two drainage tubes were placed in the chest and the wound closed

Postoperatively, the drainage tubes were placed on suction of 10 cm of water negative pressure for five days Since these became obstructed, they were removed and a new tube was placed in the upper second intercostal space anteriorly, and again this was placed on suction Thus, the pleural cavity was kept on suction for one week following operation With the removal of the intrathoracic tubes, resort was made to daily tapping and instillation of streptokinase streptodornase solution for three days In spite of all these measures, plus deep breathing exercises, the lung never expanded to fill the hemithorax completely The aspirated material rmained sterile and the patient was discharged to be followed carefully, lest empyema develop

Postoperative follow up five months following operation revealed a completely expanded lung with a pleural cap (Fig 2) Fluoroscopy showed only slight motion of the diaphragm on the left

The pathological diagnosis on the resected cystic specimen was that of "bronchogenic cyst"

DISCUSSION

The theories concerning embryogenesis of enterogenous or bronchogenic cysts of the mediastinum can be divided roughly into three types Lewis and Thyng[1] proposed embryonic diverticula or outcroppings of epithelial nodules capable of producing gastric mucosa Keith[2] felt that their existence was caused by a failure of coalescence of the vacuoles in a transverse manner, when the alimentary tube was in a solid state, resulting in a cyst which could or could not be attached to it Black and Benjamin[3] expressed the belief that these cysts were intrathoracic vestiges of the vitelline duct Calling attention to the common genesis of epithelial lining of the respiratory and digestive tract, Olken[4] indicated difficulty in making a diagnosis as to origin on this criterion alone This writer pointed out further that all mediastinal cysts were closely related embryologically, however, he added, the esophageal cysts seemed to form a rather distinct group They are almost invariably found in an adult, situated in the lower half of the esophagus, usually between the muscle layers of the esophageal wall, and the epithelium is composed of ciliated cuboidal cells with occasional foci of flattened epithelial cells Histologically, these cysts resemble most closely the group described as of bronchogenic origin, except that they contain no cartilage It would be expected that these cysts would cause symptoms secondary to pressure on the contiguous mediastinal structure Dyspnea cough, cyanosis, pleurisy dysphagia can all be produced in some degree in this manner However, the more alarming clinical syndromes are due to another

THE ONE-BREATH OXYGEN TEST ADAPTED FOR USE WITH DIFFERENTIAL BRONCHOSPIROMETRY

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THE one-breath oxygen test described by Comroe and Fowler[1] has proved a valuable method for measuring uneven alveolar ventilation We have modified the described test by discarding the flowmeter to obtain the volume curve The Lilly flowmeter is expensive, the fine mesh is easily affected by condensation of water vapor, the unevenness of the curves suggests the presence of artifacts, and the calculation of volume is laborious To measure the volume of expired air, we use a 7 L well-balanced respirometer Over the shaft of the pulley is attached a potentiometer of 360 degrees, low torque and 10,000 ohms*, connected to a Sanborn Poly-Viso recorder The contact voltage is provided by a 1 5 volt battery and rheostat The curve for volume of gas expired is linear in the range and rates of flow used for the test Simultaneous recording of flow and the curve from the nitrogen meter allows one to calculate easily the percentage rise of the nitrogen curve The points 750 c c and 1,250 c c are generally used, as recommended by Comroe, but the occasional patient is unable to expire in this range When this occurs the same increment may be used at lower points provided they fall on the alveolar plateau

Fig 1 shows a typical abnormal test taken from a patient with moderate emphysema The upper portion of the figure on the left shows the standardization of 0 per cent to 80 per cent nitrogen. On the right is the nitrogen curve showing the inspiration of 100 per cent oxygen, the expiration of dead space air, the rising curve representing the mixture of dead space air and alveolar air and the so-called alveolar plateau on which is calculated the 8 per cent rise of nitrogen in 500 c c of alveolar air The dotted line indicates a normal curve for comparison The lower portion of the figure shows the gas flow curve from which perpendicular lines are drawn at 750 c c and 1,250 c c of expired air It is important to have the patient expire evenly and slowly to compensate for the slight lag in the nitrogen meter

We have used the one-breath oxygen test in screening over 100 patients before pulmonary resection There is good correlation between this test, a prolonged timed vital capacity, and reduced maximum breathing capacity with spirographic curve elevated to the hyperinflation level All patients with elevated ratio of residual air to total capacity and increased index of intrapulmonary mixing had grossly abnormal one-breath oxygen tests

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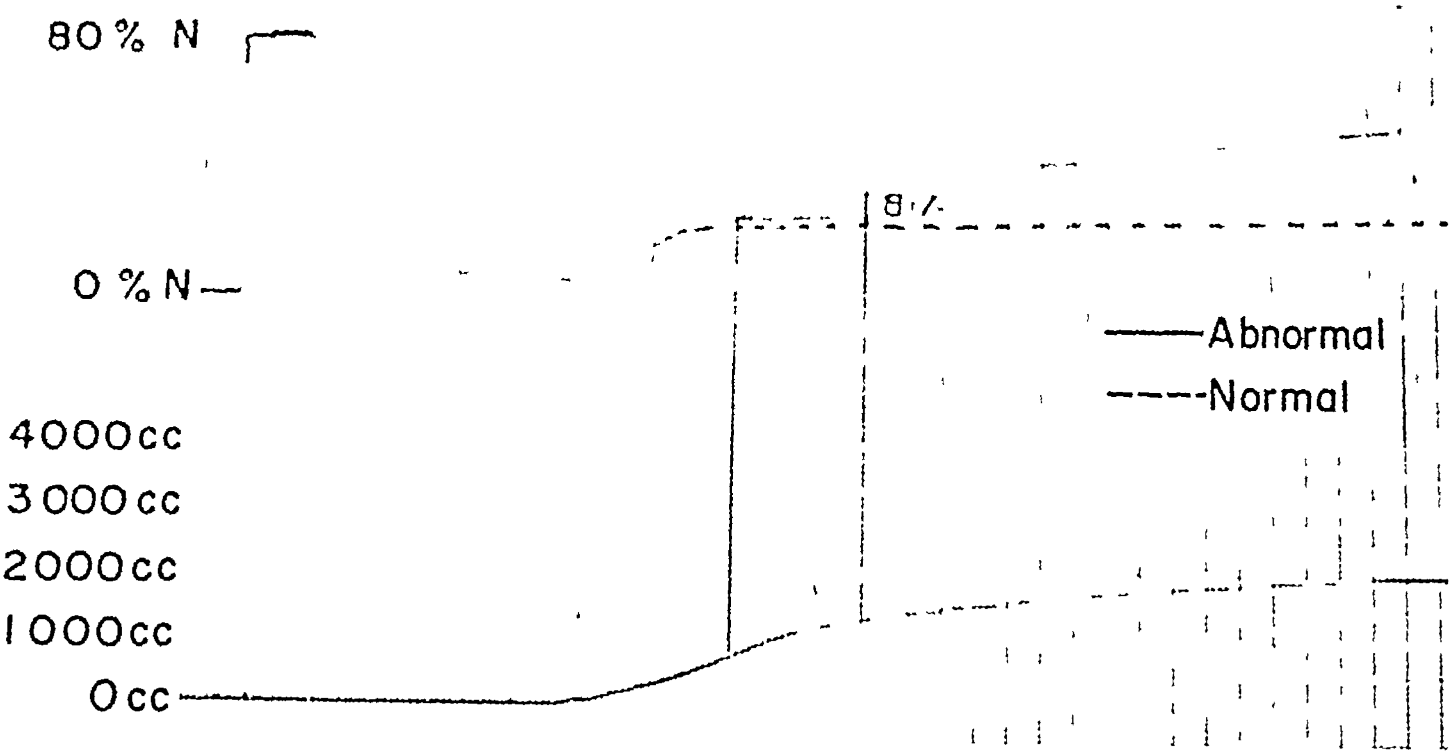
From The Veterans Administration Hospital Madison Wis
Received for publication Feb 16 1955

*Giannini

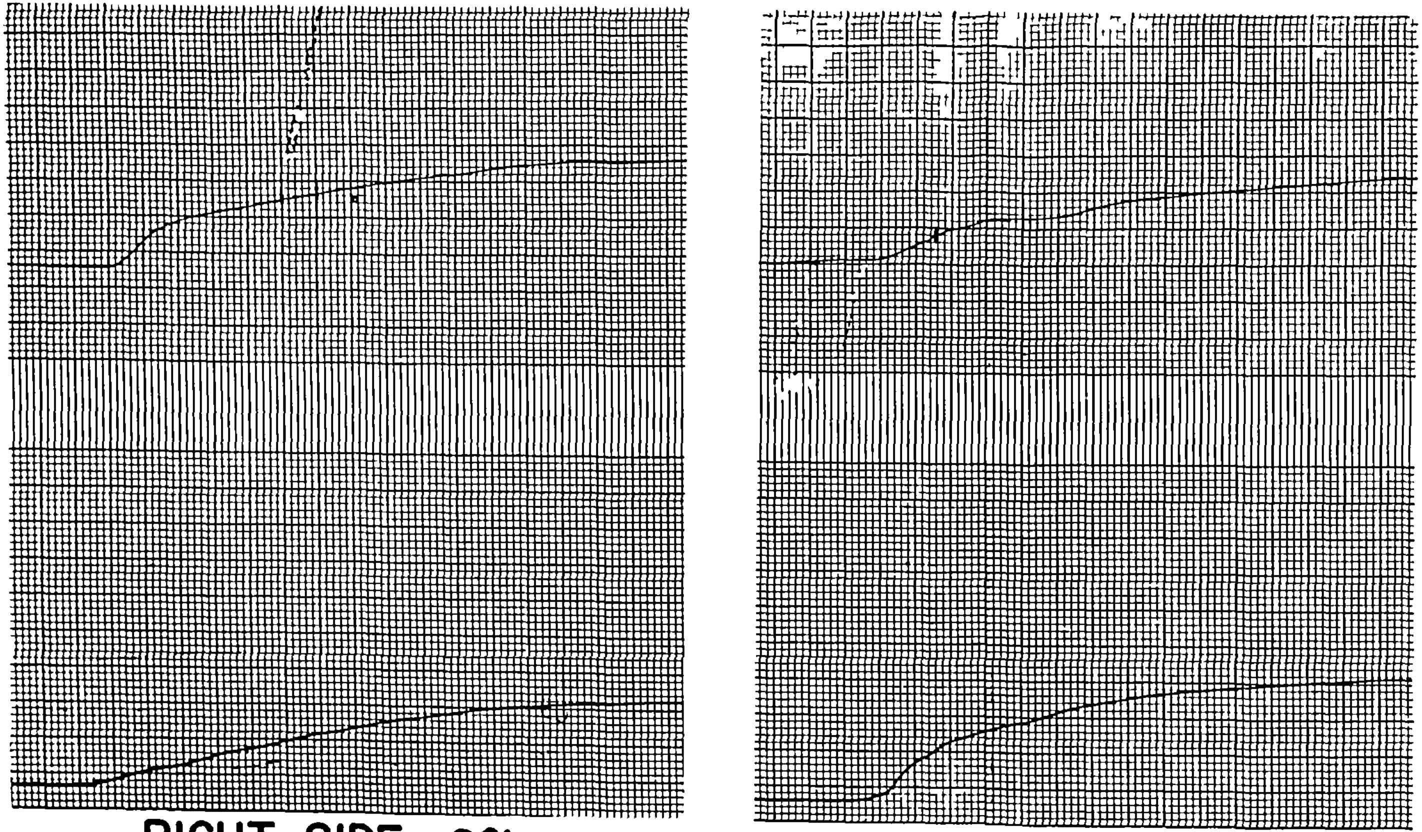

80% N
0 % N
4000cc
3000cc
2000cc
1000cc
0cc
8%
Abnormal
Normal

Over 50 per cent of our patients undergo pulmonary resection for residual tuberculous lesions. Many of these receive lobectomies without thoracoplasty or plombage. We have undertaken a long-term study to determine whether the remaining overexpanded lung develops emphysema. We have scanty pathologic evidence that this occurs, but the rapidity, extent, and frequency of these changes are not known. A change from a normal one-breath oxygen test before pulmonary surgery to an abnormal curve postoperatively might indicate the development of poor intrapulmonary gas distribution and suggest the possibility of some emphysema. It then becomes important to determine which lung is involved and to measure the degree of abnormality.

Differential bronchospirometry will provide comparison between the two lungs for ventilation, vital capacity, and oxygen uptake. The seven-minute nitrogen washout test of Darling[2] is not practical for bronchospirometry because of the length of time necessary to complete the tests bilaterally. A patient will rarely tolerate bronchospirometry for more than a few minutes and hyperventilation occurs in many of them during the procedure. The one-breath oxygen test is ideally suited to bronchospirometry. The test is completed quickly without further discomfort to the patient. Nitrogen curves of the expired gas from each lung are obtained which allow direct comparison and analysis.

METHOD

Bronchospirometry is performed according to the standard technique using a Gebauer or Carlen double lumen catheter.[3] The tubes of the catheter are connected to a Collins bronchospirometry assembly with two respirometers. On the pulley shaft of one of these is fitted a potentiometer connected to a Sanborn Poly-Viso recorder as described previously. The needle for the nitrogen sampler is inserted into the connecting couple just above the end of the catheter tube. The tubing leading to the Waters Conley nitrogen meter is 12 inches in length. The output from the amplifier is connected to another channel on the Poly-Viso. The potentiometer and nitrogen meter are carefully standardized during the time the patient is receiving the local anesthesia in preparation for the insertion of the catheter. After the catheter is in place the three-minute run on room air is made, during which ventilation and oxygen uptake are obtained. Then the catheter is disconnected from the respirometer assembly. The respirometer tubing is interchanged so that oxygen may be breathed out of one respirometer and the expired gas is collected in the other respirometer with the potentiometer attachment. The inspiratory tubing on the latter respirometer is stoppered with a cork to prevent gas leakage. When all is in readiness and the respirometer bell is filled with 99.4 per cent oxygen, the patient is asked to take a deep breath of room air and to exhale completely. He is then connected with the oxygen circuit and he is again asked to take a deep breath, at which time the Sanborn recorder is started. He then exhales slowly and evenly into the second respirometer while the nitrogen curve and expiratory volume are recorded. The same procedure is repeated for the opposite side by merely interchanging the catheter tubes. Usually one recording from each side suffices. Occasionally the patient may cough during the



RIGHT SIDE 8%

LEFT SIDE 5%

Fig. 3.—Bilateral one breath oxygen tests which show rising curves of alveolar nitrogen from both lungs of Patient L. T. A.

buttock X ray of the chest revealed moderately advanced pulmonary tuberculosis The sputum was positive for acid fast bacilli From November, 1949, until the present time he had received several courses of antimicrobial therapy In 1952, because of positive secretion, he had a series of operations performed at another hospital Sept 18, 1952, right upper and middle lobectomies, Oct 13, 1952, thoracotomy for closure of broncho pleural fistula, Nov 18, 1952, thoracotomy and drainage of empyema, Oct 13, 1953, thoracoplasty, 7 ribs, and paraffin pack Subsequently the paraffin sloughed via the tracheobronchial tree and through the thoracotomy wound On July 6, 1954, an incision and drainage of a chest wall abscess was performed The last positive secretions were found in May, 1953 On admission to this hospital he was continued on Isoniazid, 100 mg three times a day, and para aminosalicyclic acid, 12 Gm daily, but in view of possible further surgery, he was begun later on Viomycin, 2 Gm, twice weekly, and Isoniazid, 100 mg three times daily Because of a persistent air pocket in the right apical region (Fig 6) and some bronchiectasis of the remaining right lower lobe, the Surgical Board recommended the completion of a right pneumonectomy Pulmonary function studies were as follows fluoroscopy showed a right thoracoplasty The right diaphragm was elevated and adherent to the lateral chest wall There was some movement of the medial portion The left diaphragm moved well Vital capacity was 1,971 c c, or 55 per cent of normal Three second timed vital capacity was 78 per cent Maximum breathing capacity was 54 L, or 57 per cent of normal Spirograms showed prolonged expiration on vital capacity test and maximum breathing capacity performed at hyperinflation level One breath oxygen test revealed a rising curve of alveolar nitrogen to be 8 per cent in 500 c c Oximeter studies showed the peripheral blood to be 95 per cent saturated with oxygen while breathing room air When the saturation was lowered to 80 per cent by rebreathing from a respirometer gradually depleted in oxygen, it took 75 seconds to return to 90 per cent

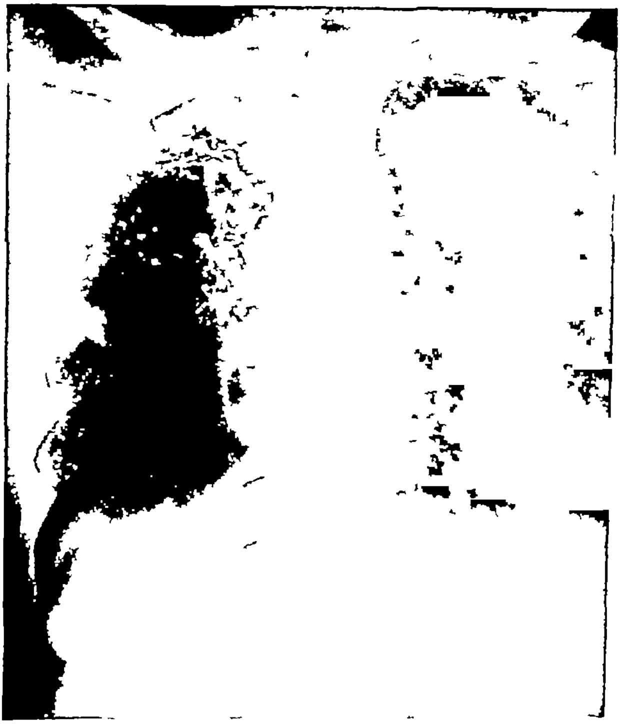
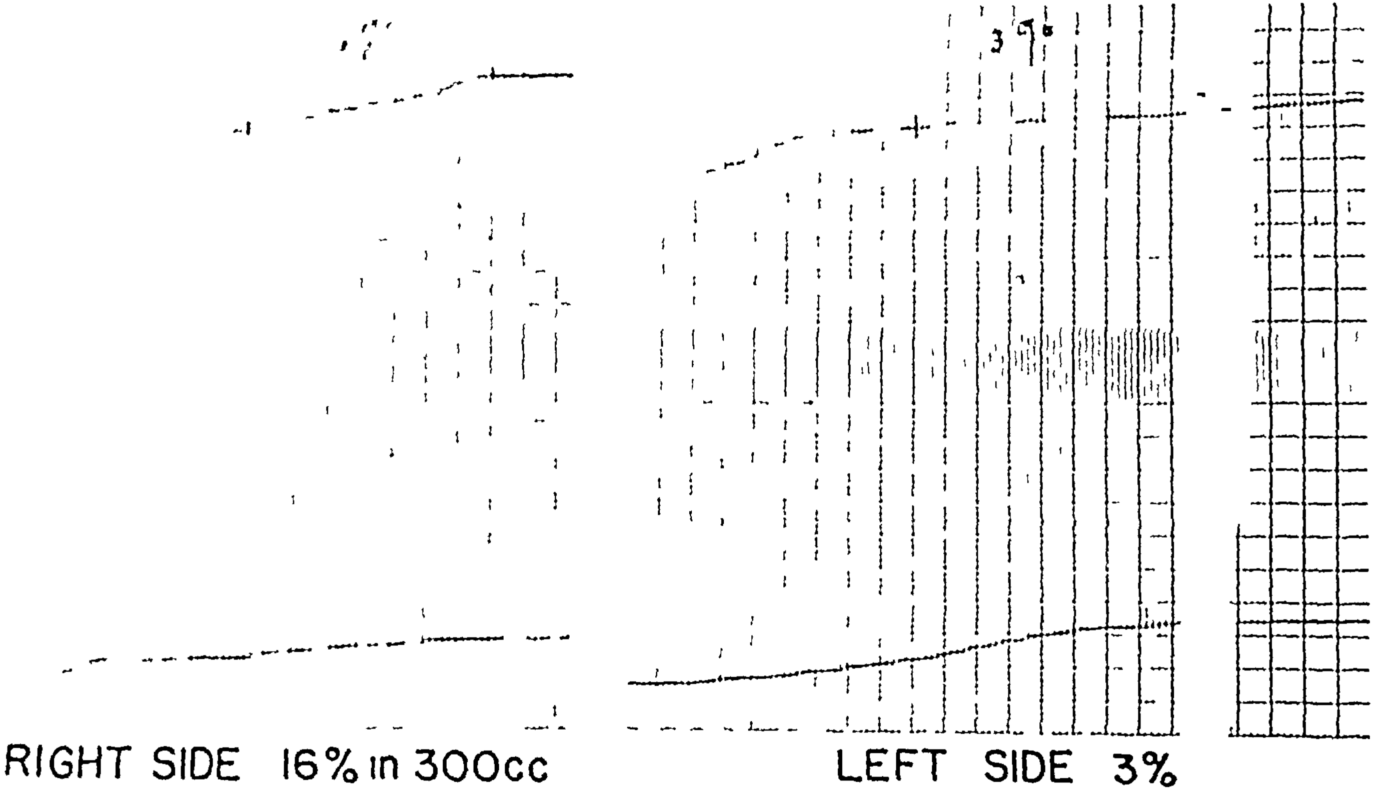


Fig 4 —Bronchogram of Patient M T which demonstrates extensive bronchiectasis of right upper lobe



[illegible] alveolar nitrogen from the right lung saturation when allowed to breathe room air again (normal less than 24 seconds)[4] Differential bronchospirometry showed ventilation on the right side of 36 per cent, vital capacity 22 per cent, and O uptake 59 per cent The one breath oxygen test showed a rising curve on the left with 8 per cent in 500 c c (Fig 7) but only 1 per cent in 200 c c on the right side

Comment—This patient was scheduled for completion of right pneumonectomy Because of slight dyspnea on ward activity, his alert physician requested careful pulmonary physiologic appraisal The finding of good oxygen uptake on the right was unexpected The poor function on the left was explained by the emphysema and uneven gas distribution which was demonstrated by differential bronchospirometry Surgery was deferred

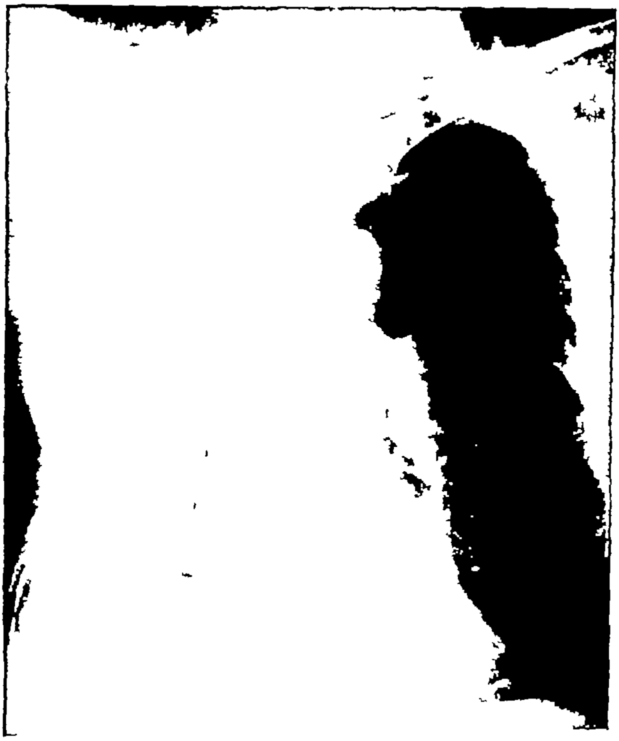
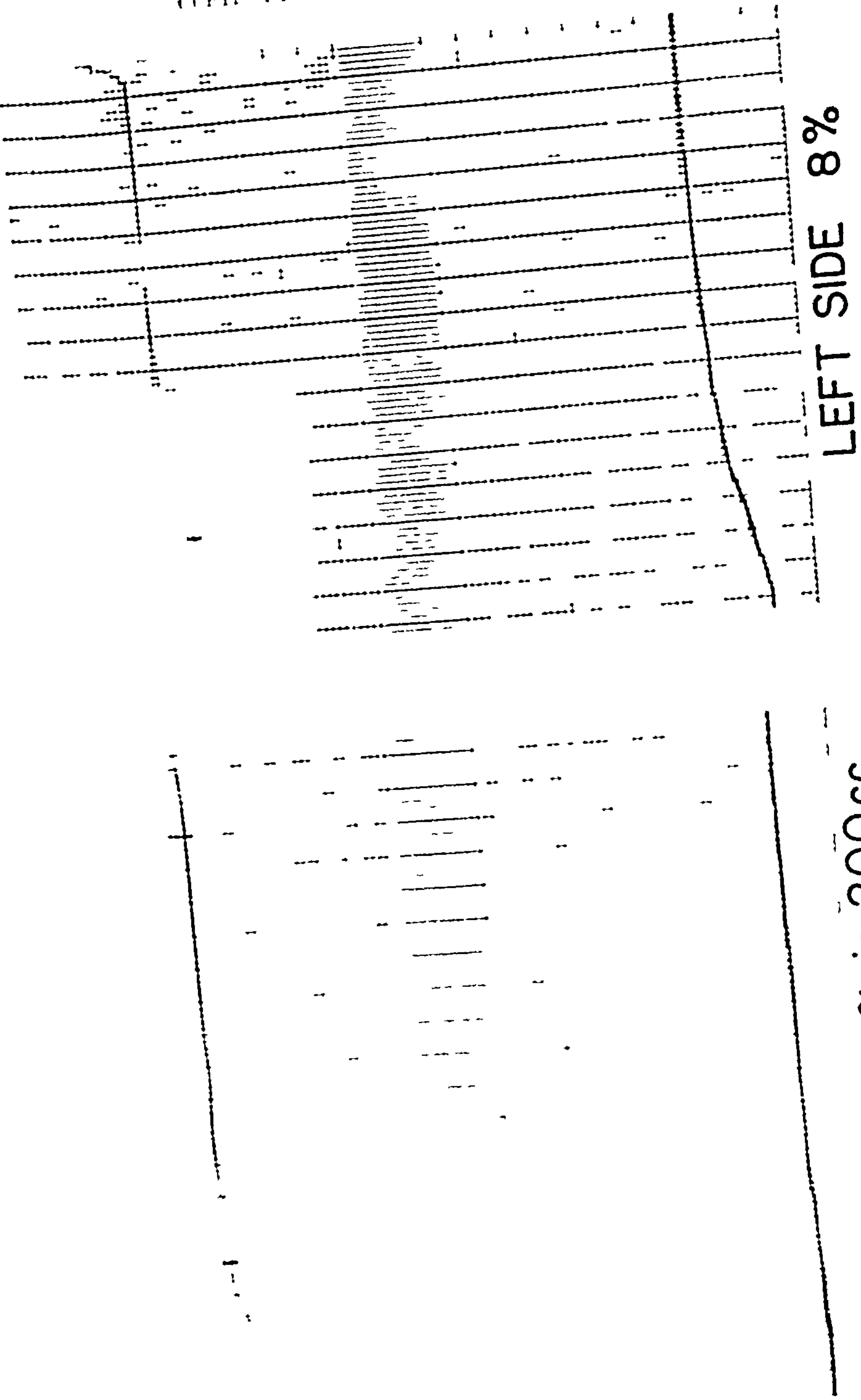


Fig 6—Chest x-ray of Patient S H which shows right thoracoplasty and extra and intra pleural air pockets at right apex.

DISCUSSION

The alveolar nitrogen curves obtained from each lung separately during differential bronchospirometry allow one to compare the gas distribution of the right and left lungs The importance of making such observations is well illustrated by the three cases presented We believe this method will be helpful in determining changes in the overexpanded lung following lobectomy without thoracoplasty or plombage

It will be noted that the dead space is considerably reduced by the catheter so that the alveolar plateau is reached after expiration of about 300 c c of air This allows one to take points at less than 750 c c and 1,250 c c which would not be available on lungs severely compromised by disease When


LEFT SIDE 8%
RIGHT SIDE 1% in 200cc

less than 500 c c is available on the alveolar plateau, smaller amounts may be used The configuration of the curves, however, from the two sides provides useful evidence of uneven gas distribution, even without making the calculations

SUMMARY

1 The one-breath oxygen test of Comroe is a sensitive indicator of alveolar gas distribution

2 This test has been adapted to differential bronchospirometry

3 Three case histories are presented which illustrate the value of obtaining bilateral alveolar nitrogen curves after one breath of oxygen

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THE POSTOPERATIVE STATUS OF THE DEPENDENT LUNG

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Frederick W. Dasch, M.D.
Philadelphia, Pa.

A ROENTGENOGRAPHIC study of the lungs in the period immediately [illegible] thoracic surgery was undertaken because of interest aroused by [illegible] in re-expansion noted in the lung upon which surgery had been [illegible]. Unexpected findings in the contralateral lung in the first [illegible] studied led to further roentgenographic investigation of the effects of [illegible] surgical position per se on the aeration of the dependent lung.

A review of the literature failed to reveal any similar studies, although [illegible] studies[2] were reported on surgical position in relation to respiratory [illegible], carbon dioxide retention, etc.

METHOD OF STUDY

The study was conducted at Eagleville Sanatorium, Eagleville, Pennsylvania, [illegible] 200-bed sanatorium devoted to the treatment of pulmonary tuberculosis. [illegible] of the Radiology Department to the operating rooms made it [illegible] roentgenograms on the unconscious patient within [illegible] minutes [illegible] wound closure. Patients were taken in their respective operative positions [illegible] operating table directly to the Radiology Department across the hall from [illegible]

[illegible] three tuberculous patients were studied, 19 of whom were [illegible] [illegible] had been performed in [illegible] cases. The lateral decubitus [illegible] in 27 instances and the prone or supine position in 5. [illegible] surgical procedure [illegible] as follows:

[illegible]

still connected to the anesthesia apparatus After films were taken in the lateral decubitus position the patients were turned to the supine position and other roentgenograms were exposed

Of the 5 pneumonectomies, 4 had been performed in the prone (Overholt) position, and 1 in the supine position All 5 were x-rayed in their respective positions while on controlled respiration The patient whose operative procedure had been done in the supine position was turned to the lateral decubitus position and a film was exposed immediately Because of the nature of the Overholt position, it was not possible to shift the position of the 4 patients operated on in the prone position

Three different anesthesiologists participated in this study Pentothal sodium was used for induction Syncurine was added before intubation Closed circuit manually controlled ether-oxygen was administered during the resection Nitrous oxide-oxygen was substituted during closure Secretions were aspirated and the lungs were reinflated at frequent intervals throughout the operation

RESULTS

All roentgenograms on patients whose surgical procedures had been carried out in the lateral decubitus position revealed evidence of increased densities which varied from patchy infiltrations (Fig 1, *B*, Case 1), to complete homogeneous opacity of the dependent lung The exposed lung was consistently free of such abnormalities (Fig 2, *B*, Case 2)

These findings were more pronounced in the films taken when the patients had not been turned from the lateral decubitus position (Fig 2, *B*, Case 2) There was marked clearing immediately after turning to the supine position (Fig 2, *C*, Case 2)

In patients operated upon in the supine or prone position the contralateral lung was well aerated and free of compression However, in Case 3, poor aeration in the remaining lung developed immediately when the patient was turned to the right lateral decubitus position for 1 minute (Fig 3, *C*)

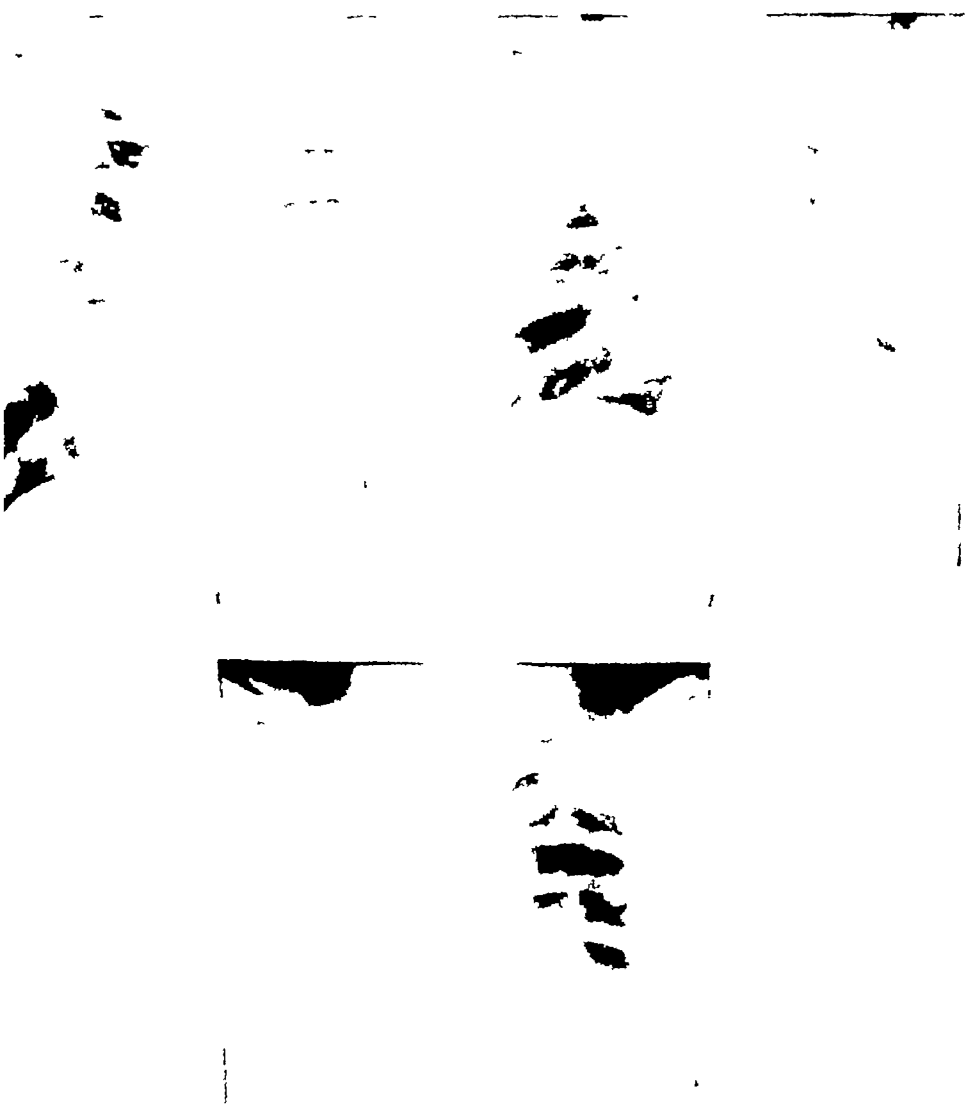
In the patient who had had closed pneumonolysis, roentgenograms of the contralateral lung revealed increased density throughout the lung (Fig 4, *B*, Case 4)

DISCUSSION

The roentgenographic abnormalities of the dependent lung in patients operated upon in the lateral decubitus position were probably due largely to three factors—compression from above downward by the weight of the mediastinal structures, elevation of the diaphragm by weight of abdominal contents (Fig 4 *B*, Case 4), and immobilization of the dependent hemithorax by the weight of the patient's body

The vector effect of the three factors mentioned greatly reduces the volume of the dependent lung and therefore alveolar ventilation Restricted movement favoring accumulation of secretions and patchy atelectasis may also be involved In our small series the effects described were independent of the extent of tuberculous involvement, the type of surgery, or the duration of anesthesia

It is of interest to note the rapidity with which the generalized haziness [illegible] in the dependent lung in Case 3 when the patient was turned from



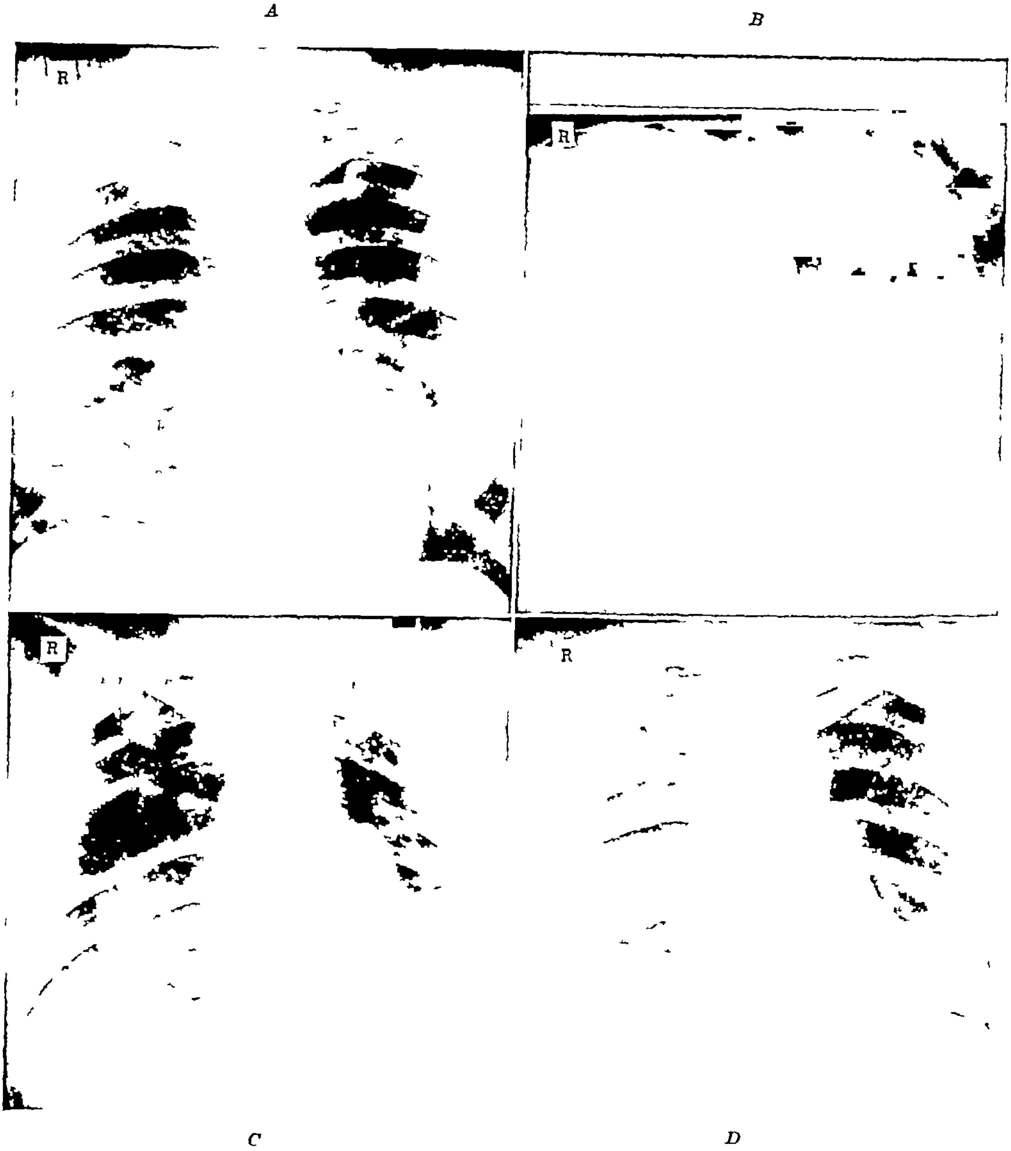


Fig. 2.—Case 2. A. S., a 35-year-old white man.

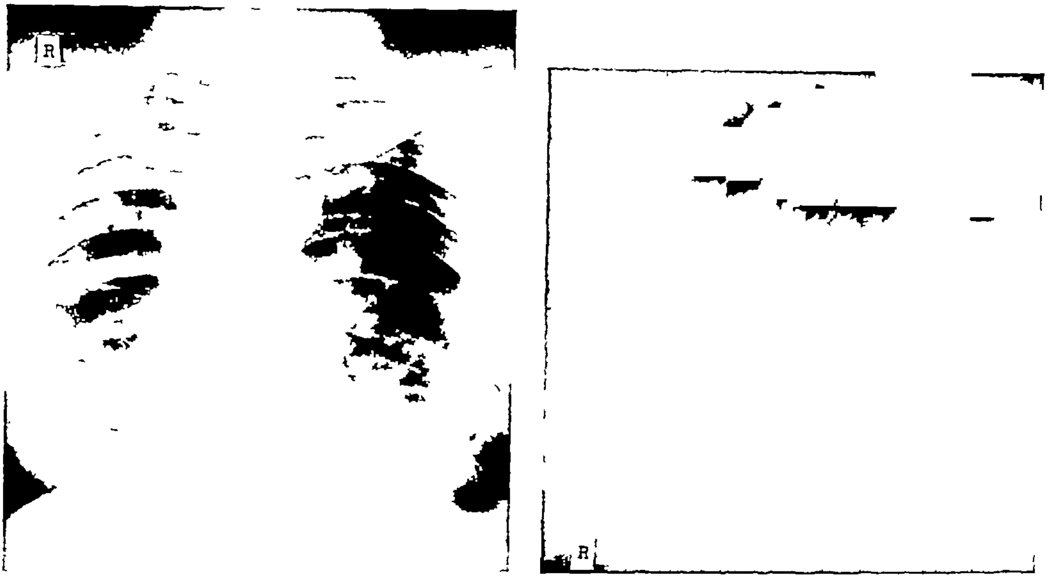
A, Preoperative film taken on April 24, 1954, reveals disease in the right apex; sputum positive.

B, Left lateral decubitus film exposed immediately following resection of the apical and posterior segments of the right upper lobe, April 26, 1954. Operation had been performed in the left lateral decubitus.

C, Anteroposterior film exposed in the supine position within 1 minute after the patient was turned from the left lateral decubitus position. Note that clearing has started in the left lung.

D, Erect posteroanterior film taken the first postoperative day reveals clear left lung and normal postoperative reaction in the right lung.

the supine to the lateral decubitus position The rapidity with which the dependent lung reverted to normal when the patient was turned from the lateral decubitus to the supine position was also impressive (Fig 2, *C*, Case 2)



A *B*

Fig 4 —Case 4 G C a 47-year old Negro man

A Preoperative film exposed on April 3 1954 reveals a left artificial pneumothorax with apical adhesions

B Anteroposterior film exposed in the right lateral decubitus position immediately after left thoracoscopy under Pentothal sodium anesthesia. The adhesions could not be cut. Note the changes in the dependent right lung and the elevation of the right diaphragm

SUMMARY

1 Thirty-three patients who had undergone thoracic surgery were x-rayed immediately postoperatively in various positions

2 The changes in the dependent lung are described

3 Possible mechanisms involved in changes observed are described

We wish to thank Drs Seymore Schotz, Demetrius Kostrubiak, and Basil Rozhin, the participating anesthesiologists, for their assistance, and Dr J Gershon Cohen and his associates for their roentgenographic interpretation Also our thanks are expressed to Dr Katharine R Boucot, for her editorial assistance

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Table I

	0 10 YEAR	10 20 YEAR	20 30 YEAR	30 40 YEAR	40 50 YEAR	50 60 YEAR	TOTAL
Number	2	10	40	30	16	8	106
Died	1	–	2	1	1	1	6
			>1*				>1*
Relapse	–	–	2	–	–	–	2

*This case must be added to both groups

During sanatorium treatment 6 patients died (6 per cent) After discharge 3 patients (3 per cent) had a relapse, one of whom died

The indications for operation are shown in Table II

Table II

		DURING SANATORIUM TREATMENT			AFTER DISCHARGE FROM TREATMENT	
	NUMBER	DIED		EMPYEMA	RELAPSE	DIED
Primary tuberculosis	3	1		–	–	–
Ulcerative phthisis	8	–		–	–	–
Tuberculomas	1	–		–	–	–
Tuberculous bronchitis	13	1		–	1	–
Cavities	49	–	1*	1	1	1
Destroyed lung and/or empyema	32	2	1*	2	–	–
Total	106	4	2*	3	2	1

*This number must be added to both groups

DIED

Primary tuberculosis

1—H J, a boy, 4 years old There was a gland perforation in the right main bronchus with obstruction pneumonia in the entire right lung He died from shock on the second day following operation

Tuberculous bronchitis

2—L M, a woman, 40 years old There was stenosis of the left main bronchus She died on the twelfth day following operation from bronchopneumonia of the right lung

Cavities

3—B R, *a man, 54 years old* Pneumonectomy was performed on the left side During the operation, a large cavity perforated A tuberculous empyema developed with a bronchial fistula He died eight months after operation

4—J L, a woman, 29 years old The patient had pneumonectomy performed on the left side and had had previous dissemination in the right lung She was discharged in good condition A year after the operation, she developed a cavity on right side The patient died two years later

Destroyed lung

5—B B a man, 28 years old The patient had a destroyed lung with tuberculous empyema and bronchial fistula on the right side After pleuro pneumonectomy, tuberculous empyema appeared again plus a bronchial fistula He died eighteen months after operation

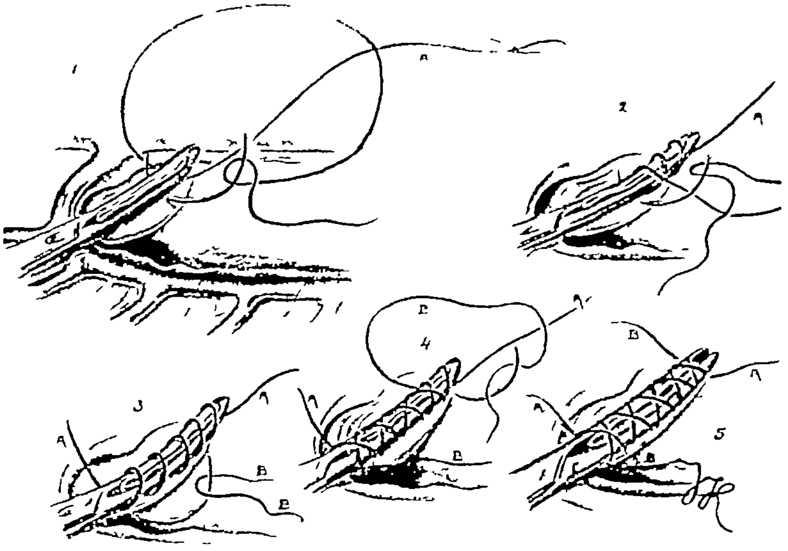


Fig 1

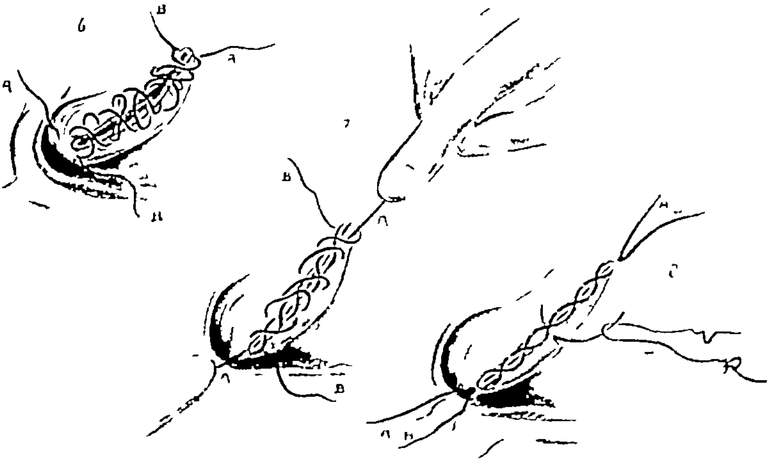


Fig 2

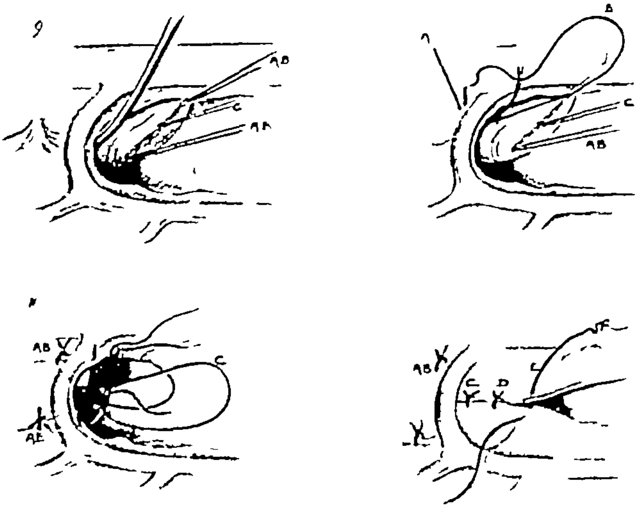


Fig 3

TABLE V

NUMBER OF SUBJECT (FIGS 1 11)	SUBJECT	SEX	AGE (YEARS)	STATURE (M)	PNEU MONEC TOMY R/L	THORACO PLASTY	POSITION OF DIAPHRAGM	DISPLACEMENT OF MEDIASTINUM† AND TIME BETWEEN PNEUMONECTOMY AND LUNG FUNCTION TESTS IN MONTHS									
1	I M	m	38	1 79	L	–	Phrenic exeresis during pneumonectomy	I	5	I	69	I	102				
2	R A	f	28	1 67	L	–	Phrenic exeresis during pneumonectomy	0	16	0	28	0	57	0	75	0	86
5	S S	f	32	1 53	L	–	–	I	8	I	48	I	76				
6	J V	f	26	1 83	L	–	–	III	16	III	42						
7	M E	f	19	1 74	R	2d 7th rib included *during* pneumonectomy	–	0	23	0	39	0	51				
8*	A S	f	23	1 57	L	–	–	I	7	I	18	I	30	I	49		
9*	S H	f	24	1 53	L	–	High position of left diaphragm	I	7	I	16	I	29				
10	C D	m	59	1 73	R	–	Phrenic exeresis during pneumonectomy	0	16	0	29	0	49	0	60		
12	A H	f	24	1 59	R	–	–	II	8	II	32						
13*	W S	m	47	1 76	R		–	0	7	0	22	0	35	0	53		
16*	G G	f	20	1 42	L		–	I	7	I	21	I	37	I	52		
17*	W B	m	23	1 76	L	–	High position of left diaphragm	0	6	0	12	0	29	0	42	0	52
18	T A	m	24	1 78	R	–	–	0	6	0	23	0	51				
19*	W N	f	39	1 65	R	–	–	0	5	0	18	0	36				
21*	K M	f	47	1 55	L	–	–	I	4	II	17	II	35				
22*	B L	f	17	1 77	L	–	–	0	4	I	17	I	35	I	47		
23	H H	m	34	1 78	R	–	–	0	33								
26*	T V	m	32	1 65	L	1st 7th rib 10 months before pneumonectomy	High position of left diaphragm	0	10	0	32	0	46				

The question remains, however, as to whether stretching of the remaining lung gives rise to emphysema and reduces lung function. Some authors express the view that this is, indeed, the case. They base this opinion on the studies of Longacre and co-workers,[10-12] Bremer,[13] and Cournand and associates.[14-16] It appears, however, that these workers exercise great caution in their conclusions in this regard. Birath and associates[17] state, "The fears of emphysema that have been expressed in connection with this distention received only slight confirmation in the cases examined." Gaensler and Strieder[18] have also compared results of lung function in patients with and without thoracoplasty after pneumonectomy. They say, "Thoracoplasty accomplished just the opposite of the desired result. The range of the useful respiratory movement (VC) was greatly reduced, whereas the volume which merely dilutes the inspired tidal air (residual volume) was only slightly reduced . . . [from 38 to 35 per cent of the total capacity]. Worst of all, the initial mean MBC of 58 liters per minute was permanently reduced to 46 liters per minute." Mathey and co-workers[19] emphasize this conclusion and consider the value of a thoracoplasty after pneumonectomy very doubtful.

We also studied the function of the remaining lung. In 38 of the 63 patients who underwent pneumonectomy more than two years ago (Table IV), we have been able to do, and to repeat at different times, lung function tests. These 38 patients are listed in Table V. Twenty patients were women, 18 men. Pneumonectomy was performed 24 times on the left side and 14 times on the right. Age at time of operation was as follows:

2 between 10 and 19 years
17 between 20 and 29 years
11 between 30 and 39 years
6 between 40 and 49 years
2 between 50 and 59 years

Three of these 38 patients had a thoracoplasty performed. In the female patient, No. 7, six ribs, the second up to and including the seventh, were removed during pneumonectomy. The operation was performed elsewhere and the patient was sent to our sanatorium because, notwithstanding the thoracoplasty, a small cavity developed contralaterally. In the male patients, Nos. 26 and 34, thoracoplasty, comprising seven ribs, was performed elsewhere ten months and two years respectively, prior to pneumonectomy. Both patients, however, had residual cavities in the collapsed area, so the diseased lung finally had to be removed.

In 4 patients phrenic exeresis was done. In patients No. 1 and No. 2, this was done during the pneumonectomy because we believed, at the beginning, it offered certain advantages—being influenced by the literature mentioned previously. These, however, were the only patients in whom phrenic exeresis was purposely done. In patient No. 10, the phrenic nerve was accidentally cut during surgery and in patient No. 40, phrenic exeresis had been done twenty-one years previously. After examination, it appeared that patients Nos. 9, 17, 26, 27, 73, and 74 all had a highly positioned diaphragm on the side operated upon, probably as the result of contraction.

TABLE VI SUBDIVISION OF THE TOTAL CAPACITY (T C) IN ADULTS

AGE	VITAL CAPACITY* IN % T C	FUNCTIONAL RESIDUAL VOLUME IN % T C	RESIDUAL VOLUME IN % T C	RESERVE VOLUME IN % T C	TIDAL VOLUME IN % T C	COMPLEMENTARY CAPACITY IN % T C	USABLE PART OF VITAL CAPACITY* IN %
20 39 yrs	75	40	25	15	11	49	83
40 49 yrs	72	43	28	15	11	46	75
50 59 yrs	68	47	32	15	11	42	70
60 70 yrs	65	50	35	15	11	39	70

*Vital capacity = complementary capacity + tidal volume + reserve volume

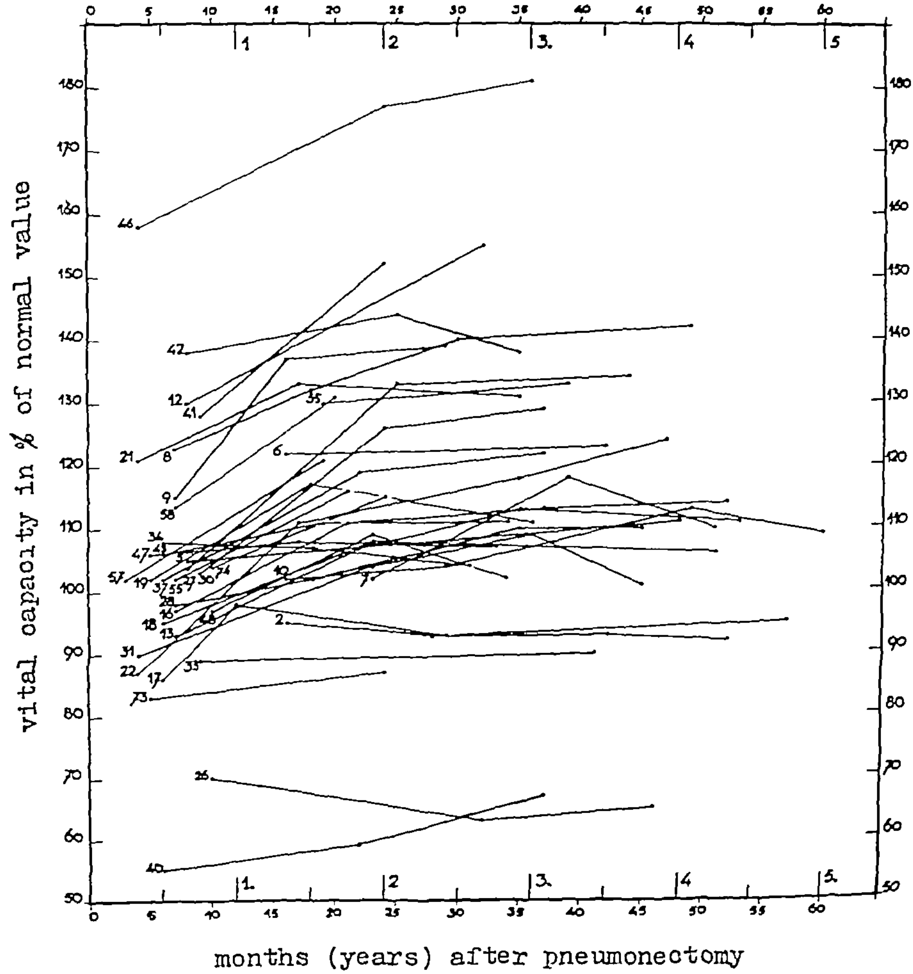
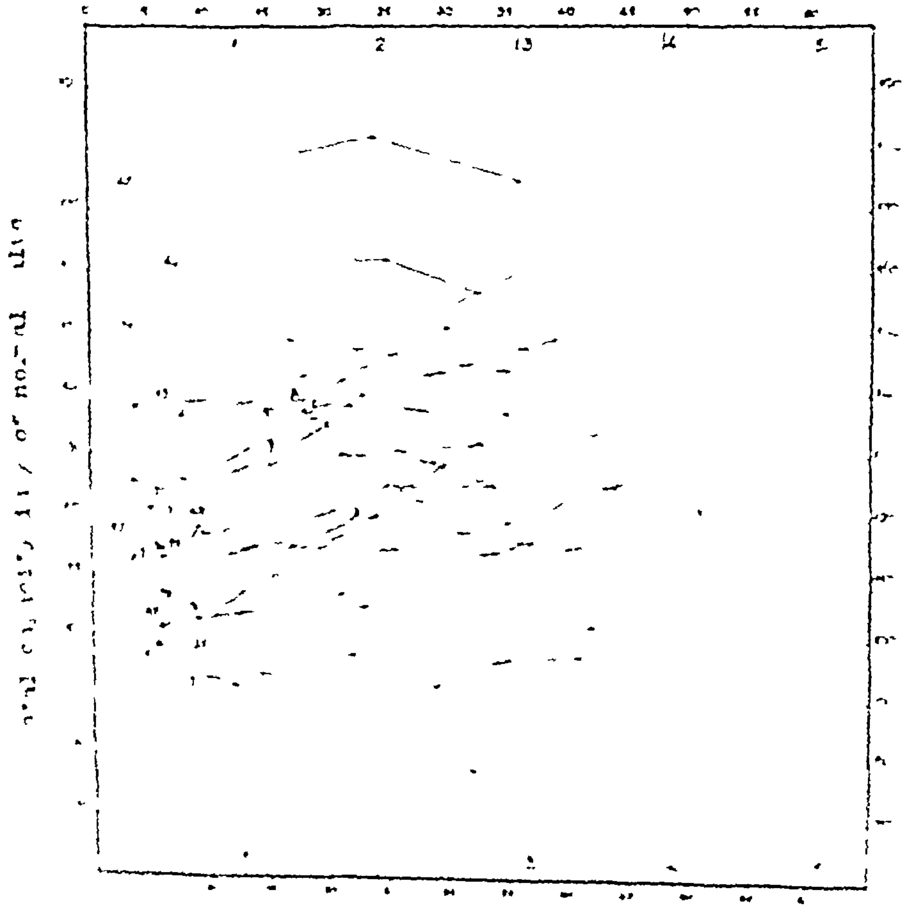


FIG 4

In accordance with this method Figs 4 (vital capacity) and 5 (total capacity) have been compiled, whereby each line represents the volume alteration with the time after the operation The numbers of the lines correspond to the numbers of the patients in Table V

In Fig. 4 it is evident that the vital capacity of the majority of the [illegible] exceeds 100 per cent, and with few exceptions more [illegible]. During the first year after operation (Fig. 4) the maximum [illegible] expressed in percentages of the normal value lies between 90 and 105 per cent; in the second year between 100 and 115 per cent. During the third [illegible] becomes of smaller numbers and the large spread [illegible] is lost.



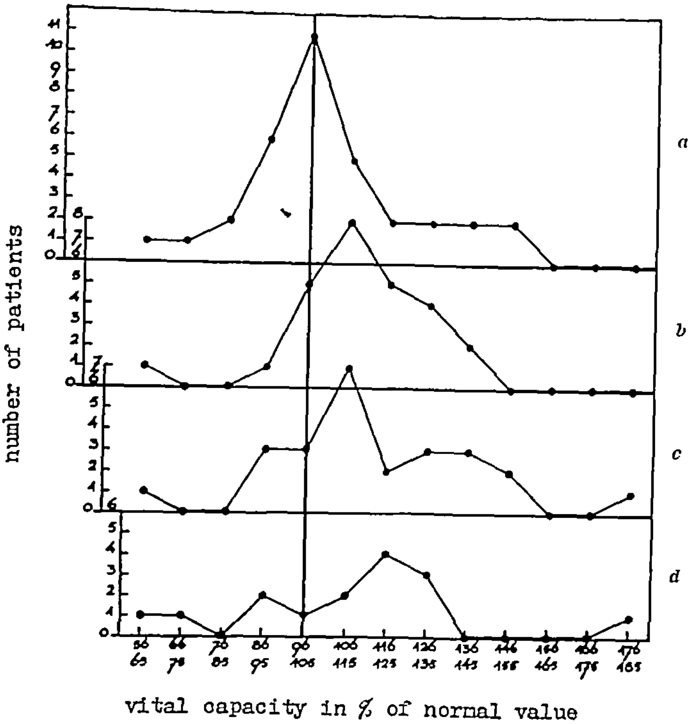


Fig 6

a Within 12 months after operation 32 patients
b Between 13 and 24 months after operation 26 patients
c Between 25 and 36 months after operation 25 patients
d, Between 37 and 48 months after operation 15 patients

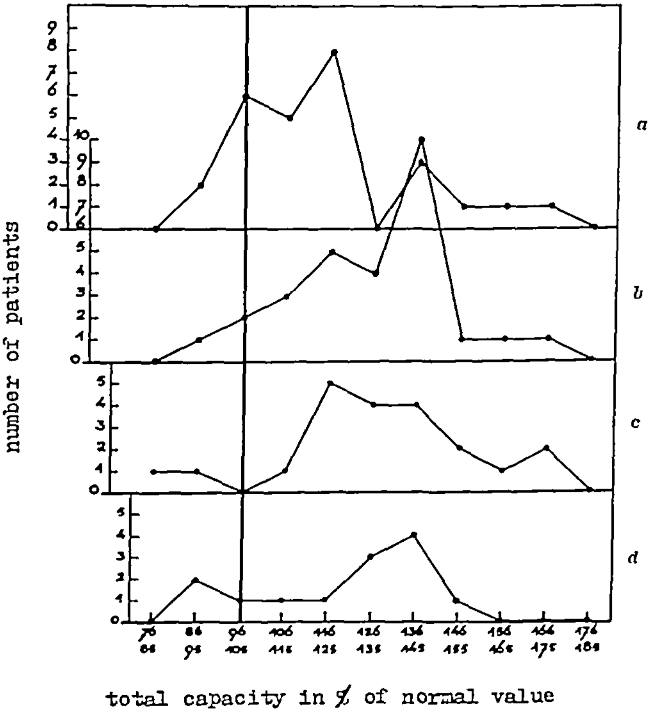


Fig 7

a *Within 12 months after operation 27 patients*
b Between 13 and 24 months after operation 28 patients
c Between 25 and 36 months after operation 21 patients
d Between 37 and 48 months after operation 14 patients

examined, of whom 30 were younger and 8 older than 40 years The spreadings-curve (Fig 9) confirms the fact that there is no increase of the residual volume in percentage of the total capacity

The normal values of the maximum breathing capacity (M B C) in liters were calculated according to the formula of Hirdes and van Veen [28]

$$\frac{\text{vit cap in ml}}{1{,}000} \times \text{usable part of the vit cap in } \% \times 30$$

The normal value for the usable part of the vital capacity employed in this formula is indicated in the last column of Table VI This factor was introduced by Tiffeneau and Drutel[29] and is comparable to the "one second value" of Gaensler [30] The values obtained for the M B C were expressed in the same manner in percentages of the normal values of the remaining lung as is described for both the vital capacity and the total capacity In Fig 10 the curves of the change of the M B C of the individual patients have been reproduced The majority lie around 100 per cent and here, once more, we observe, as in the case of the vital capacity, a tendency to increase in the course of time In the spreadings curve of the M B C (Fig 11) this is evident only in a reduction of the number of cases below 100 per cent This shows that the ventilatory reserves become larger, a fact that is favorable for working conditions

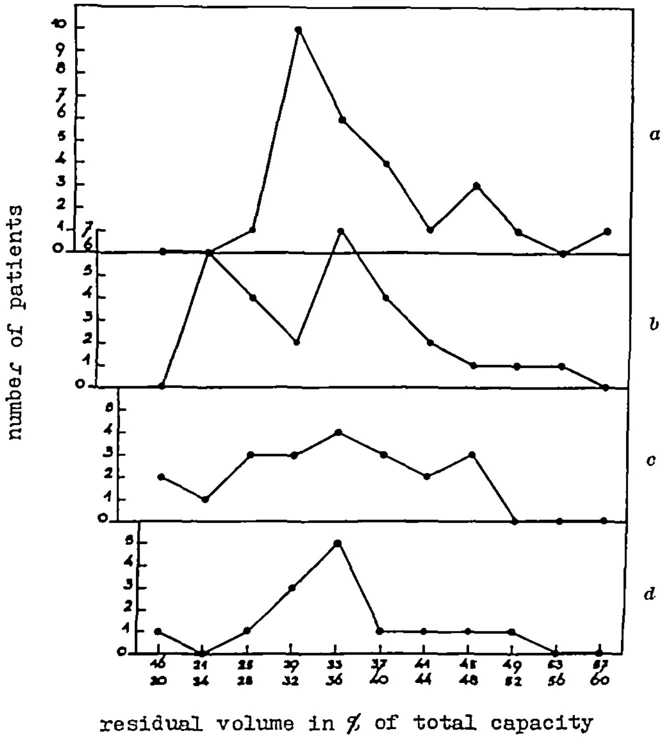


Fig 9

a Within 12 months after operation 27 patients
b Between 13 and 24 months after operation 28 patients
c Between 25 and 36 months after operation 21 patients
d Between 37 and 48 months after operation 14 patients

each patient, including the time after pneumonectomy Although there are a number of patients who have too low a value (<70 per cent), there is no general tendency to further reduction This is confirmed by the spreadings curve (Fig 13) In general, therefore, one cannot speak of a loss of elasticity of the lung

All of the patients marked with an asterisk in Table V had complete lung function tests in the first, second, and third years after operation, so their average values during successive years could be calculated These average values of the total and vital capacity, the residual volume, the M B C, and the usable part of the vital capacity demonstrate clearly the tendency which has already been observed in the different curves (Fig 14)

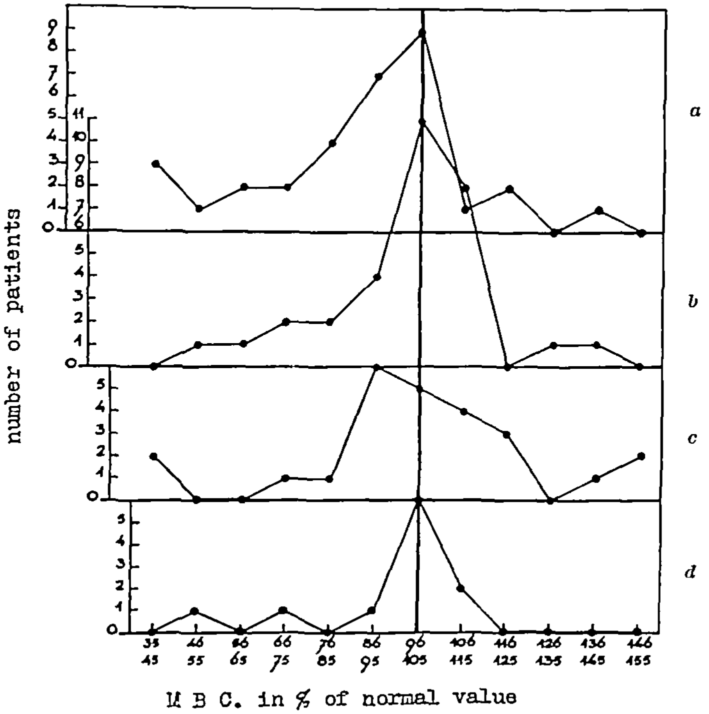
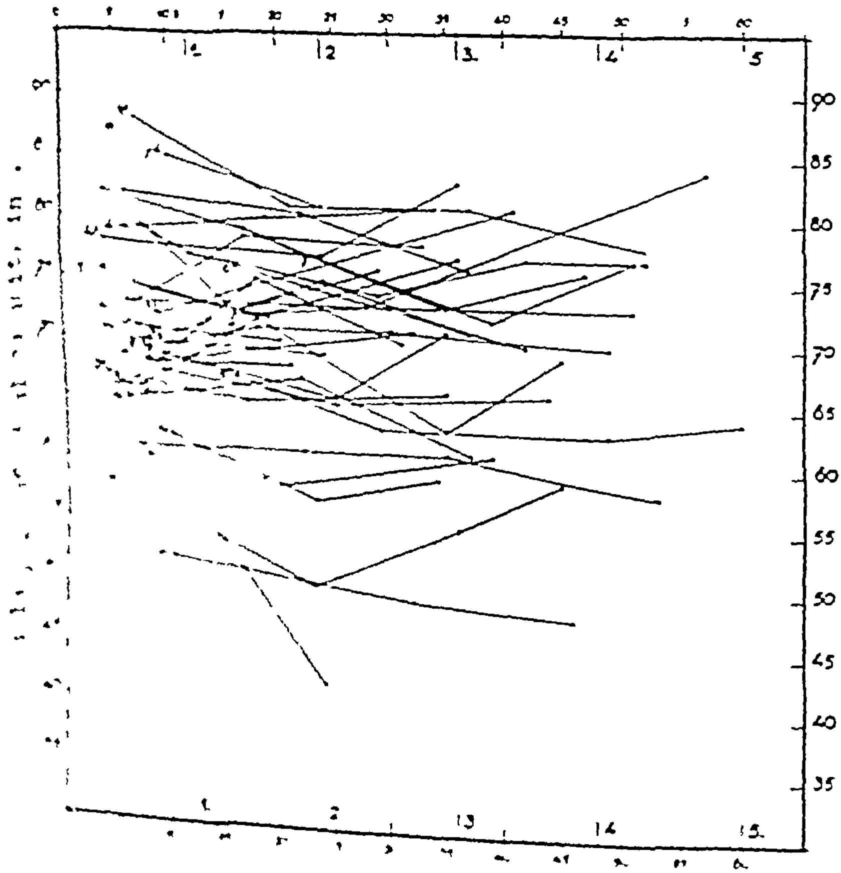


Fig 11

a Within 12 months after operation 30 patients
b Between 13 and 24 months after operation 31 patients
c Between 25 and 36 months after operation 22 patients
d Between 37 and 48 months after operation 11 patients

The fairly high percentage for the average residual volume of all 18 patients (line 1 of Fig 14) requires further explanation For this purpose we divided the patients into two groups (Table VII) The first group, of which the residual volume during the first examination was equal to or smaller than 36 per cent of the total capacity, was composed of 9 patients The average age of this group was 25 years The second group, with a residual volume larger than 36 per cent of the total capacity during the first examination, was also composed of 9 patients Their average age was 39 years The age of the pa-

[illegible] pneumonectomy appears to influence directly the size of the [illegible] operation There are no other distinct differences between [illegible] which would explain the marked difference in the average resid- [illegible] group includes 3 pneumonectomies on the right side and 6 [illegible] there is one patient in whom the pneumonectomy was [illegible] In the first group patient No 34 had a seven rib thoracoplasty [illegible] the pneumonectomy This is the only patient whose residual [illegible] years became larger In the second group in the female [illegible] No 40 [illegible] was performed twenty one years prior to and on [illegible] the pneumonectomy It is due to the phrenic exeresis that such [illegible] residual volume was seen in this patient



[illegible] after pneumonectomy

TABLE VII RESIDUAL VOLUME AT FIRST INVESTIGATION AFTER PNEUMONECTOMY

<36 PER CENT OF TOTAL CAPACITY					>36 PER CENT OF TOTAL CAPACITY				
		RESIDUAL VOLUME IN % TOTAL CAPACITY					RESIDUAL VOLUME IN % TOTAL CAPACITY		
SUBJECT	AGE (YEARS)	1ST YEAR	2ND YEAR	3RD YEAR	SUBJECT	AGE (YEARS)	1ST YEAR	2ND YEAR	3RD YEAR
16	20	29	22	27	13	47	52	44	41
17	23	36	24	27	19	39	44	39	48
22	17	29	27	23	21	47	39	33	31
27	23	29	20	19	26	32	47	40	40
30	20	25	22	25	31	34	39	34	40
34	47	31	34	42	37	24	37	37	36
42	31	36	34	33	40	42	59	56	51
43	26	36	37	31	47	37	37	37	39
46	20	32	27	25	48	53	46	47	48
Mean	25	31	28	28	Mean	39	44	41	41
		TOTAL CAPACITY IN % OF NORMAL VALUE							
Mean		119	128	129	Mean		122	126	129
		VITAL CAPACITY IN % OF NORMAL VALUE							
Mean		110	124	125	Mean		93	102	103
		USABLE PART OF VITAL CAPACITY IN %							
Mean		76	75	74	Mean		66	65	65
		M B C IN % OF NORMAL VALUE							
Mean		105	106	109	Mean		78	79	84

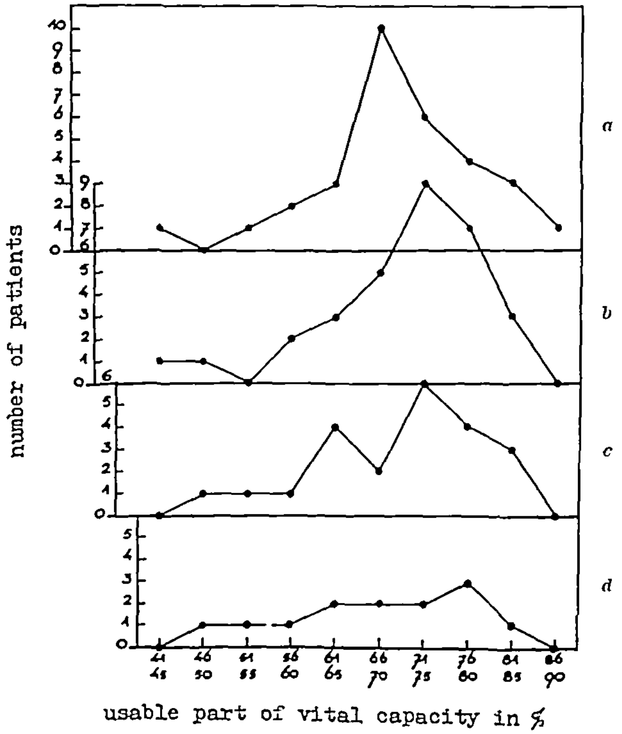


Fig. 13

a, Within 12 months after operation 31 patients
b Between 13 and 24 months after operation 31 patients
c Between 25 and 36 months after operation 22 patients
d Between 37 and 48 months after operation 13 patients

considerably below the normal value This resembles, up to a certain point, the so called old age emphysema, for with normal and more elderly persons the total capacity remains constant and the residual volume increases at the cost of the vital capacity Here the usable part of the vital capacity and the M B C diminish and to an equal extent, precisely as in the group of older patients

How can this be explained? It is possible that among the older group of patients there are those whose illness is of longer duration The chances that disseminations in the remaining lung have taken place, which have given rise to fibrosis and emphysema with all the resulting functional changes, are hereby enhanced We have not been able to find in the x-ray pictures any support for this assumption Proof of an enlarged residual volume in the contralateral lung prior to pneumonectomy is absent, because no reliable method exists of measuring separately the residual volume and the total capacity of each lung

Another possibility is that the larger residual volume in the older patients can be explained as due to a degenerative emphysema resulting from overstretching Opposed to this is the fact that the large residual volume was observed at the first examination, within a year after pneumonectomy Such a quick occurrence of these alterations in the structure of the lung tissue seems improbable There are also the reduction in residual volume and the increase in vital capacity in the course of time—a recovery, therefore, in the direction of normal These observations do not fit into the picture of a progressive degenerative emphysema

It is quite probable that the mechanical disturbance of expiration, which results from every pneumonectomy, affords a better explanation of these facts It is our belief that this disturbance in the case of young persons is compensated for in such a way that a normal residual volume can be attained, because the thoracic wall possesses possibilities of adapting itself as needed Into this picture also fits the observation that, in the course of time, the residual volume declines when these patients learn to make further use of the adaptive possibilities In older persons the disturbance of the breathing mechanism as the result of pneumonectomy will become apparent through an enlarged residual volume because the thoracic wall has become much less supple It is quite understandable that here, too, some improvement can occur in the course of time

If we grant such an important role to the functional unity of the thoracic wall and also to the diaphragm, it is not desirable to disturb this by thoracoplasty or phrenic exeresis Moreover, this might result in the ventilatory function being considerably hindered, as is demonstrated in patients No 26 and No 40

SUMMARY AND CONCLUSIONS

1 During sanatorium treatment, 6 of 106 patients died as the result of complications following pneumonectomy or pleuropneumonectomy (mortality 6 per cent)

2 Three cases of staphylococcic empyema and 2 of tuberculous empyema are reported The first 3 patients recovered, the last 2, in whom bronchial fistulas developed, died

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Erratum Requested by Dr Robert P Glover

In the article entitled "An Analysis of Fifty Patients Treated by Mitral Commissurotomy Five or More Years Ago," by Drs Glover, O'Neill, and Janton of Philadelphia, which appeared in the October issue of the JOURNAL, page 436, it is noted that a number of the patients included were only four and one half years postoperative at the time of publication so that the cases reported have actually been followed for four and one half to six and one half years

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions If the films are well labeled, it will not be necessary for the author to be present for comment

Applications for Membership

Applications for Associate Membership in the Assocation must be received by the Membership Committee not later than Dec 15, 1955, otherwise, the applications will be deferred *for consideration until the 1957 meeting*

Applicants must be sponsored by three Active or Senior Members of the Association In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to

Dr O T Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year

Aust, Joseph B (with Warden, Herbert E, Read, Raymond C, DeWall, Richard A, Cohen, Morley, Ziegler, Newell R, Varco, Richard L and Lillehei, C Walton), Direct vision intracardiac surgery by means of a reservoir of "arterialized venous" blood, 649

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Bahnson, Henry T, Discussion of experiences with surgical repair of atrial septal defects, 489

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PREPARATION OF INTERNAL MAMMARY ARTERY

(a) *Length of artery detached from chest wall.*—In our early work, the greatest number of arteries remained open and formed anastomoses when the internal mammary artery was freed from the chest wall between the fourth and sixth intercostal spaces. This principle is still followed, as we believe that when the artery is freed as far as the subclavian the risk of injury to the artery is increased and its blood supply may be jeopardized. When a long length of artery is freed, there is greater danger of angulation, kinking and twisting. We have found many arteries occluded due to narrowing at a point of angulation caused by adherence to lung, sternocostalis muscles, etc. In many of these, the artery, although narrowed or occluded at the site of angulation, was completely patent beyond this point. Injection of the implant distal to the point of occlusion in such cases has demonstrated the presence of mammary-coronary anastomoses.

In human cases of coronary artery insufficiency, it may be necessary to obtain a longer portion of the internal mammary artery when (1) there is a large anterior wall infarction, (2) the apex is in the seventh interspace, (3) the apex moves more than one interspace on respiration, or (4) there is left ventricular hypertrophy.

(b) *Excision of loose tissues in the area (sternocostalis, etc.).*—It is important to remove the sternocostalis muscles, fibrous pericardium and in many instances, the mesial fat pad in order to prevent the artery from becoming adherent to these structures after implantation, with resulting angulation and occlusion at the point of adherence.

(c) *No-touch technique.*—It is hardly necessary to remind an audience such as this that direct handling of an artery may damage the intima, thus forming a nidus for clot formation. One research center reporting a series of blocked Vineberg implants, in addition to other technical errors, routinely placed bulldog clamps on the proximal end of the vessel.[1] It is our custom never to grasp the artery with an instrument. After the sternocostalis muscles have been removed, the internal mammary artery is eased away from the chest wall by inserting a Leahy gallbladder forceps on the mesial side of the internal mammary artery and vein. In this way the internal mammary artery is carefully displaced laterally. The intercostal vessels are doubly ligated and transected close to the internal mammary artery with the exception of the sixth intercostal which is ligated and transected approximately ½ inch away from the vessel (Fig. 1, *A* and *B*). The internal mammary vein is then separated from the artery.

(d) *Preservation of periarterial tissue.*—Every attempt is made to preserve perivascular tissue. This is important because we think that branches which develop probably represent a growth of existing vascular channels around the vessel. In a series of animals, we deliberately stripped all tissues surrounding the internal mammary artery, leaving it completely bare. In this group of animals the implantation of a completely bare artery yielded not one single anastomosis.

(e) *Closure of end of artery.*—After the intercostal arteries have been tied between the fourth and sixth inclusive (sometimes between the third and sixth) the internal mammary artery is then doubly ligated and transected

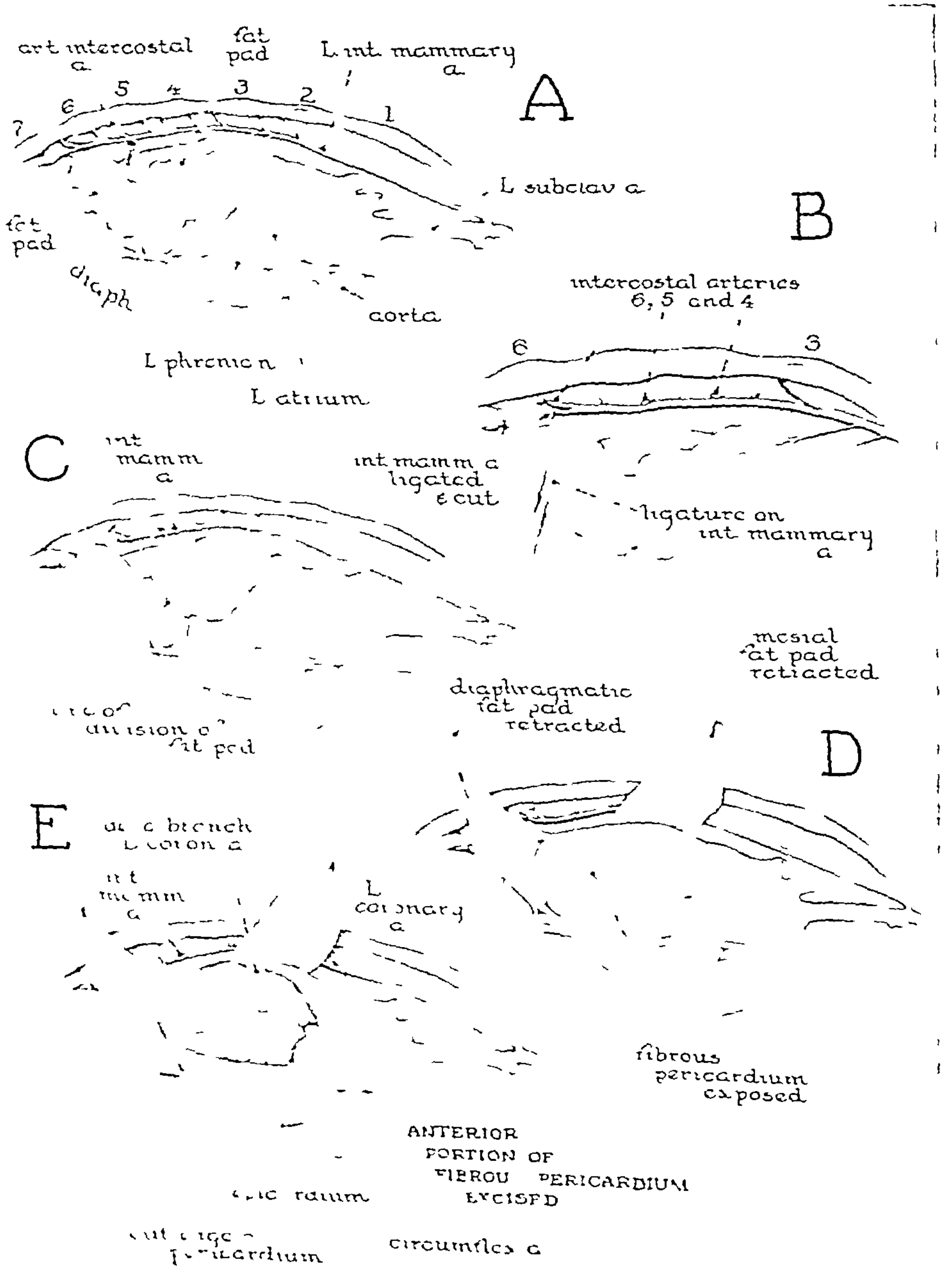

Fig. 1—Showing technique of preparation of internal mammary artery and pericardial fat pads with excision of anterior fibrous pericardium

between ligatures well beyond the origin of the sixth intercostal branch. *Zero cotton* is used, and the ligature on the proximal end of the artery is left long (Fig. 1, *B*). In placing the cotton ligatures, care must be taken to pass them behind the artery without touching it, otherwise, *there is danger of injuring* that part of the arterial wall which will lie within the myocardium. The distal end of the internal mammary artery is closed, as we believe that there is a better chance of new vessels growing out from the side of the internal mammary artery when there is a strong lateral thrust which occurs as a result of the blood column striking the occluded end of the vessel.

PREPARATION OF PERICARDIAL FAT PADS AND EXCISION OF FIBROUS PERICARDIUM

After the internal mammary artery is prepared, the three pericardial fat pads, each with its separate blood supply, are prepared by dissecting them away from the antero-mediolateral surfaces of the fibrous pericardium respectively, as shown in Fig. 1, *C* and *D*. The fibrous pericardium is then removed, starting laterally, posterior to the apex, as shown in Fig. 1, *E*. It is necessary to dissect the phrenic nerve and vessels free in order to excise the fibrous pericardium lying beneath them.

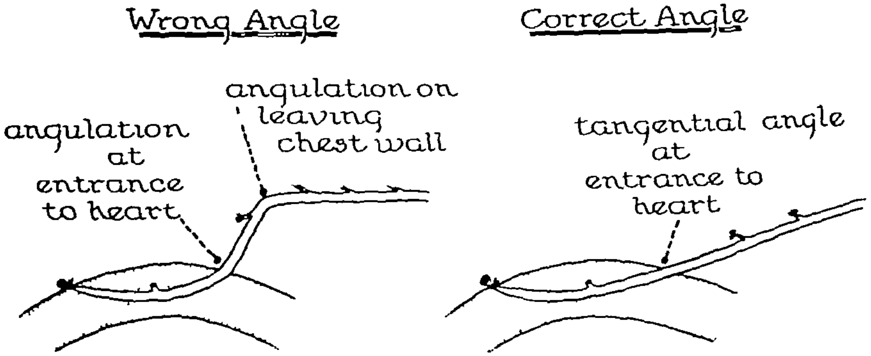
Wrong Angle
Correct Angle
angulation on leaving chest wall
angulation at entrance to heart
tangential angle at entrance to heart

Fig. 2.—Internal mammary artery implantation (anteroposterior plane).

TECHNIQUE OF IMPLANTATION OF INTERNAL MAMMARY ARTERY

(a) *Site of implantation*.—It is necessary to find a portion of the myocardium on the anterior wall of the left ventricle which is not scarred, so that the myocardial tunnel will be made into reasonably healthy muscle. In our experience, this has been possible in every instance. Recently we have had two cases with extensive anterior wall *infarctions in* which the only healthy myocardium left on the anterior surface of the left ventricle was at the base close to the division of the left coronary artery, into which the artery was placed.

(b) *Length and direction of tunnel*.—We have found that the most satisfactory length of tunnel is 1 inch. If it is made longer than this, there is a tendency for angulation to occur in the anteroposterior plane (Fig. 2). This will result in occlusion of the artery at its point of entrance into the heart.

The direction of the tunnel is likewise important and must be designed to avoid angulation in the lateral plane (Fig 3) The artery must enter the heart at a tangent avoiding acute angles in the lateral or anteroposterior planes

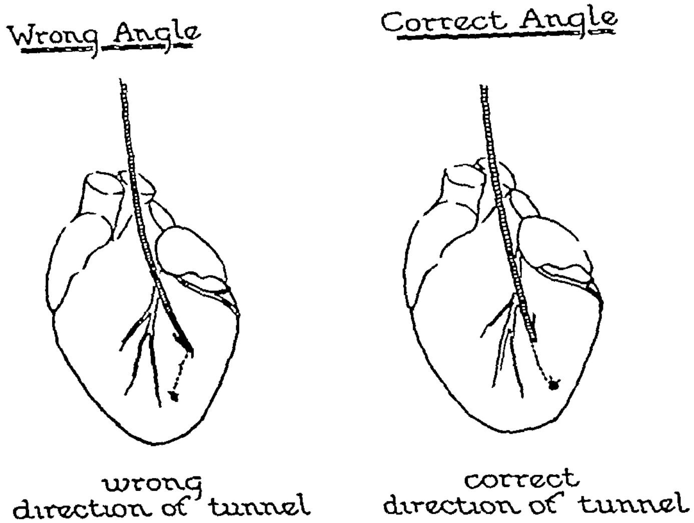

Fig 3 —Internal mammary artery implantation (lateral plane)

(c) *Method of making tunnel* —A traction suture of No 10 cotton is placed at the most distal point of the projected tunnel in the vertical axis of the heart parallel to coronary vessels This is tied loosely so as not to occlude any small vessels Immediately proximal to this traction suture the epicardium is incised with a pointed scalpel (Fig 4, *F*) A curved mosquito forceps is passed through the opening in the epicardium, and through the myocardial wall for 1 inch At the point of its emergence the forceps is spread widely to make sure that the entrance to the tunnel is sufficiently wide so as not to constrict the artery when it is pulled into position (Fig 4 *G*)

(d) *Depth of tunnel* —We have found that the greatest number of anastomoses have occurred when the artery is imbedded close to the endocardium There is however danger of opening into the left ventricle with possible thrombus formation and for this reason we place the artery approximately in the middle of the left ventricular wall

(e) *Entrance to tunnel* —In making the tunnel by means of a mosquito forceps it is important to spread the forceps widely before pulling the cotton suture attached to the internal mammary artery through into the tunnel This stretches the muscle fibers which will surround the implanted artery In a series of animals we cut these fibers and found resultant scar formation and occlusion at this location When the fibers are stretched by widening the mosquito forceps the amount of scar formation at the entrance to the *tunnel* appears to be minimal This is a very important technical point Too narrow an entrance to the tunnel will occlude the artery immediately This has been proved by placing a cannula in the end of the artery after it has been pulled into the myocardial tunnel and registering the pressure When the entrance to the tunnel was too narrow there was no flow through the artery This was relieved immediately by widening the mouth of the tunnel

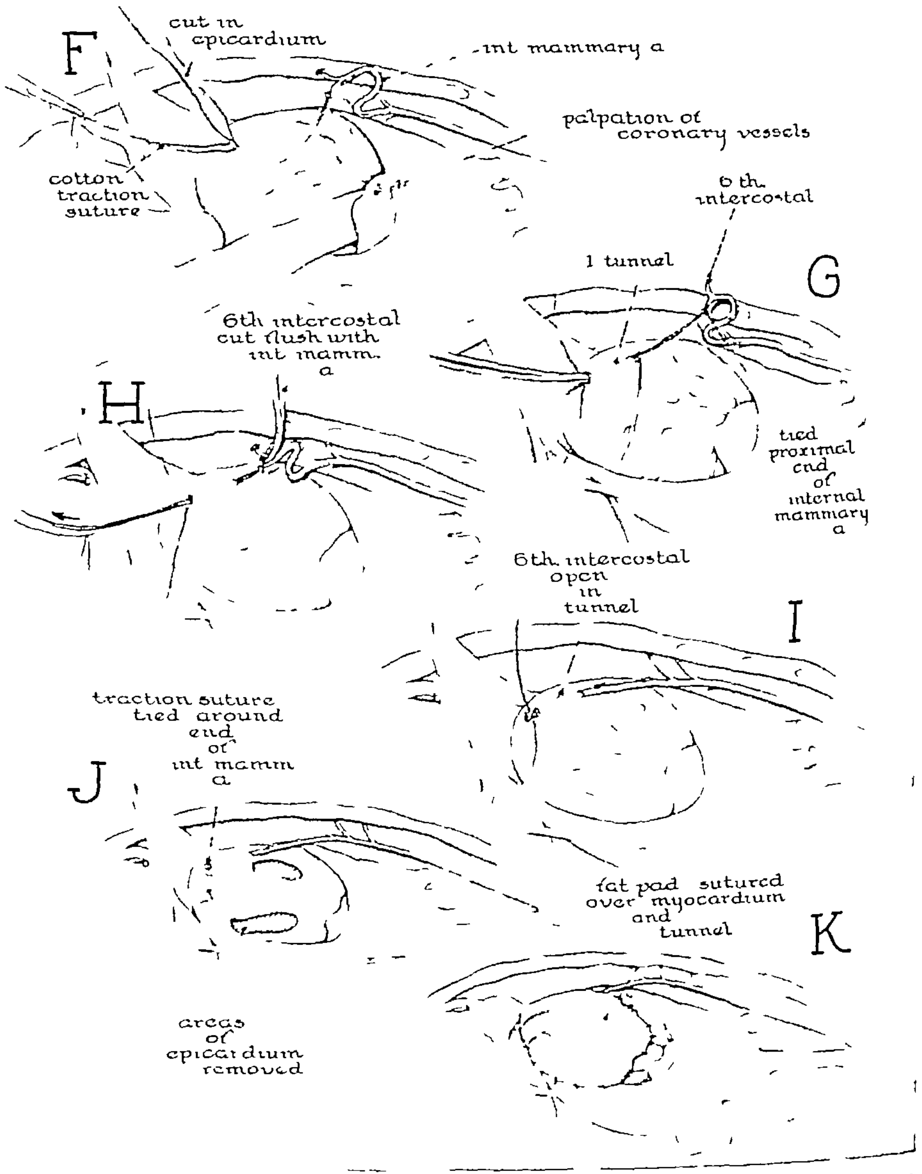
F
cut in epicardium
int mammary a
palpation of coronary vessels
cotton traction suture
6 th intercostal
1 tunnel
G
6th intercostal cut flush with int mamm a
H
tied proximal end of internal mammary a
6th intercostal open in tunnel
I
traction suture tied around end of int mamm a
J
fat pad sutured over myocardium and tunnel
K
areas of epicardium removed

Fig 4 —Shows the method of making the myocardial tunnel and implantation of internal mammary artery with placement of pericardial fat pads.

(f) *Sixth intercostal artery cut level with internal mammary artery wall.*—Before pulling the artery into the myocardial tunnel, the sixth intercostal artery which is deliberately left long is cut with a pair of curved plastic scissors flush with the artery wall. Sometimes the artery is in spasm and does not bleed. It is necessary to be sure that the adventitia around the intercostal is well removed and that an adequate opening can be seen. In early experiments the sixth intercostal was severed and left long. This was abandoned because we had evidence that the long intercostal artery tended to curl up in the myocardial tunnel and therefore might not remain open as frequently as when it was severed close to the main vessel (Fig. 4, *H*).

(g) *Fixation of artery.*—The internal mammary artery is pulled into the tunnel until it projects from the distal end. The fixation cotton suture is then tied around the internal mammary artery thus securing it in its new position. Very often there will be considerable bleeding from both ends of the tunnel; this bleeding comes from the sixth intercostal vessel and will eventually stop (Fig. 4, *I*).

(h) *Twist of artery.*—Not infrequently the artery after it has been severed twists upon itself and care must be taken in pulling the artery into the tunnel to make certain that it is not twisted. The cut ends of the catgut sutures on the intercostals will indicate quite clearly how the artery should lie.

REMOVAL OF EPICARDIUM AND APPLICATION OF PERICARDIAL FAT PAD GRAFTS DIRECTLY TO MYOCARDIAL MUSCLE

It should be pointed out that in human patients we no longer wrap the internal mammary artery in the mesial pericardial fat pad. Sometimes this pad in man (unlike in animals) is very fibrous and tough and may injure the artery. Therefore this structure is removed completely, as shown in Fig. 4, *F*. Following the implantation of the internal mammary artery, an attempt is made to remove portions of the epicardium over the anterolateral and posterior surfaces of the heart (Fig. 4, *J*). This usually can be done by means of a fine Allis forceps and scissors. The epicardium usually is removed only between coronary vessels. After this has been done the fat pads are sutured together so as to lie in contact with the bare myocardium (Fig. 4, *K*). When the lung is re-expanded it is necessary to make certain that it does not angle the artery. The chest wound is closed and the thorax drained.

CONDITION OF THE MYOCARDIUM

There is a vast difference between skeletal and myocardial muscle. The myocardium is composed of a spongelike network of vessels. When the internal mammary artery is placed in the myocardium it is placed there with an open bleeding sixth intercostal vessel. The blood from this vessel goes into the tunnel and disappears. A hematoma is never formed. In the heart due to its spongelike character blood continues to flow down the internal mammary artery and out through the slit in its wall thus keeping the artery open until it forms new branches which join with the coronary arterioles around it It is our belief that, in making the tunnel, myocardial sinusoids described by Wearn are broken into, and it is into these that the internal mammary artery bleeds (Fig 5)

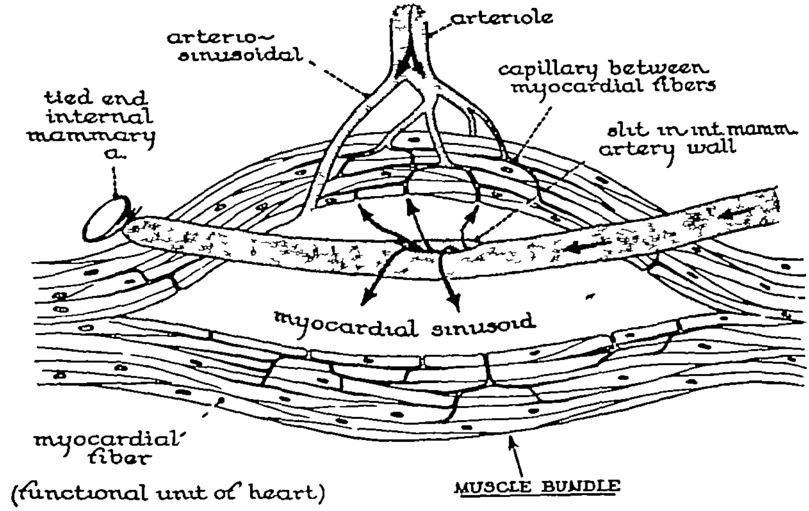
arteriole
arterio-sinusoidal
capillary between myocardial fibers
tied end internal mammary a.
slit in int. mamm. artery wall
myocardial sinusoid
myocardial fiber (functional unit of heart)
MUSCLE BUNDLE

Fig 5 —Mechanism of internal mammary artery branching within the myocardium Sketch showing myocardial sinusoid lying between myocardial muscle bundles into which the internal mammary artery is placed The myocardial sinusoidal spaces are in contact with arterioles and capillaries the latter lying between muscle fibers

This is a most important point, which is well shown in the following sections These were made through the site of implant in a human case of angina decubitus operated upon just after the meeting of this Association last year, the patient died from a penicillin reaction eighty-two hours after operation At the time of operation, certain members of this Association were present and the question was raised as to whether the artery would remain open, as it was not bleeding at the time of implantation At autopsy, the internal mammary artery was injected with India ink The ink was seen to flow through the vessels of the left ventricle Fig 6, *A* shows a slit in the artery wall with India ink in the space surrounding the vessel Note that there is no hematoma Fig 6, *B* shows India ink in the myocardial arterioles Fig 6, *C* shows the ink in large spaces lying between muscle bundle groups Fig 6, *D* shows that the India ink has reached the capillaries which lie between muscle fibers It is logical to assume that, if India ink injected into the implanted internal mammary artery eighty-two hours after operation reached muscle bundles and capillaries, blood must have been flowing along the same pathways This, we think, is a factor in preventing the artery from becoming blocked

MYOCARDIAL ISCHEMIA

When myocardial ischemia is present, theoretically it should stimulate the implant to branch and thereby increase blood flow down through the implanted artery, helping to keep it open Conversely, if there is no need for the implant, the rate of blood flow through it decreases, thereby favoring occlusion by thrombosis or intimal proliferation. In previous publications we have reported a mammary-coronary anastomosis rate of 71 per cent in ischemic hearts as compared with 46 per cent in normal hearts (Table I).

TABLE I FREQUENCY OF MAMMARY CORONARY ANASTOMOSIS
STANDARD VINEBERG IMPLANT

	NO. DOGS	ANTERIOR DESCENDING BRANCH LIGATION	SURVIVED	WITHOUT INFARCT	ARTERY OPEN	ANASTOMOSIS
NORMAL HEART	9 (Vineberg)	Not done	–	–	4	4
	6 (Niloff)	6	2	1	2	1
	11 (Miller)	11	3	7	7	8
	13 (Buller)	13	5	5	12	5
Total	39	30	10 (30%)	13	25 (65%)	18 (46%)
ISCHEMIC HEART	11 Partial ligation anterior descending branch (23 gauge needle)		8 (72.7%)	5 (45.5%)	7 (63.6%)	6 (54.5%)
	5 Cellophane wrap anterior descending branch	Exercise tolerance markedly reduced				
	Implant 3 to 4 months later	Improved			4 (80%)	4 (80%)
	5 Cellophane wrap anterior descending branch plus internal mammary artery implant	Exercise tolerance reduced in 2			2 (100%)	2 (40%) Small
		Exercise tolerance maintained at preoperative levels in 3			3 (100%)	3 (60%) Large
Total	21				16 (76%)	15 (71%)

In this table figures are shown to indicate how 65 per cent of implanted internal mammary arteries remained open when placed in normal hearts and formed anastomoses in 46 per cent. When the artery was placed in ischemic hearts the vessels remained open in 76 per cent and formed mammary coronary anastomoses in 71 per cent.

Now let us examine serial histologic sections of internal mammary arteries placed in normal hearts. Here we find, as in all implants, that the portion of the vessel distal to its open branches has a greatly reduced lumen as compared to the same vessel proximal to open branches.

Serial sections shown in Fig. 7 A and *B* were taken through a 4-month-old internal mammary implant in a normal heart. The section in Fig. 7 A was taken proximal to the open branches. There is some intimal proliferation. However, the actual lumen is still 70 per cent of the potential lumen and it measures 1.2 by 0.5 mm. This is a good sized vessel capable of delivering a large quantity of blood to the myocardium. Fig. 7 *B* shows the same vessel distal to the open branches. The lumen has been reduced to 10 per cent of its potential size. These sections indicate that an artery left in a normal heart shows intimal proliferation throughout. The extent of the proliferation varies depending on whether the section is taken proximal or distal to open branches.

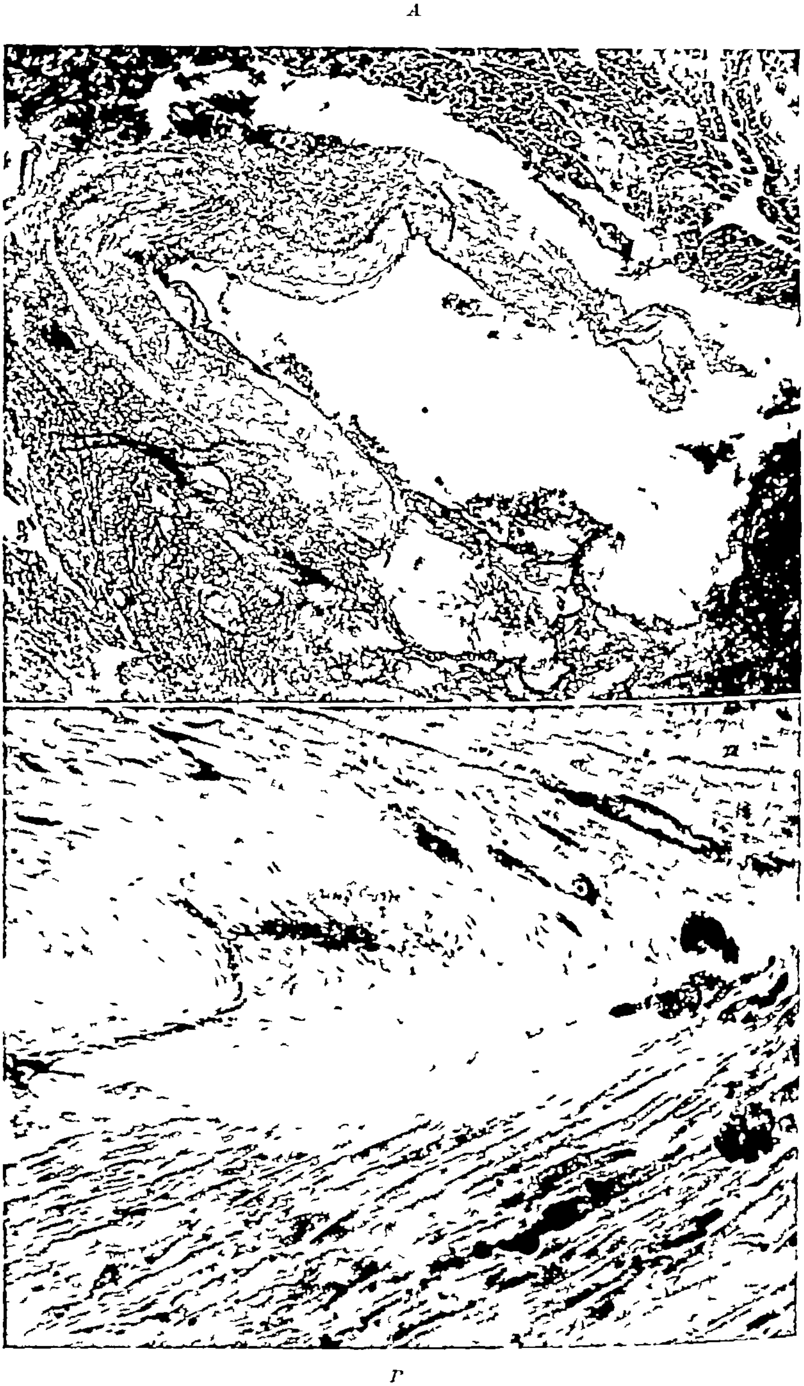

Fig 6 *A* and *B* —Internal mammary artery in myocardium of human case of angina decubitus This patient died eighty two hours after implantation from intractable bronchial spasm following a penicillin injection At autopsy the internal mammary artery was injected with India ink *A* Note the slit in the arterial wall with India ink in the space surrounding the vessel There is no hematoma *B* Note India ink filling the arterioles

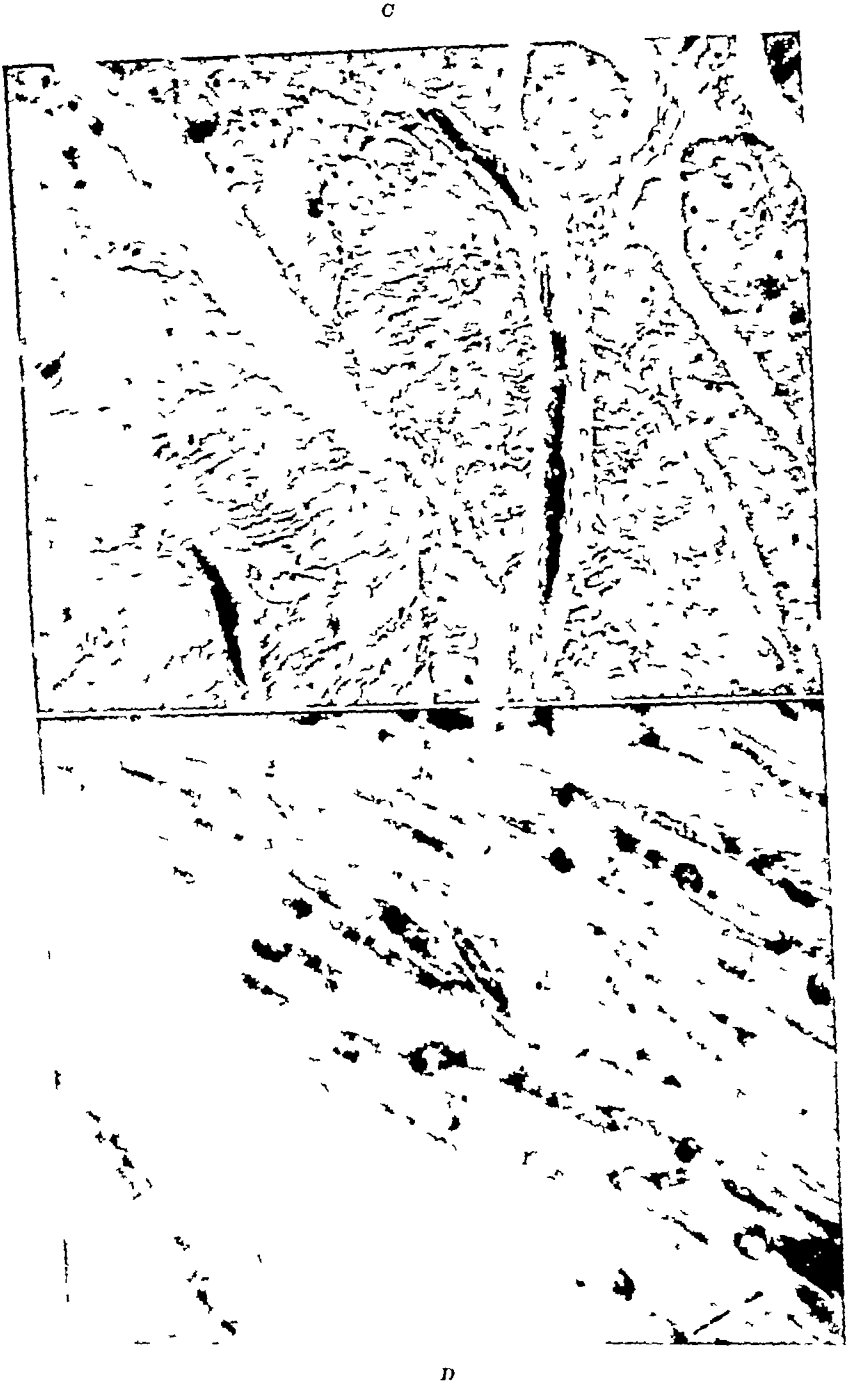

Fig. [illegible], C and D.—Same patient as in Fig. [illegible], A and B. C, Note how the India ink is lying in large spaces between muscle bundle groups. These may be myocardial sinusoids filled with India ink. D, Note how the India ink injected through the internal mammary artery has reached the capillaries which lie between muscle fibers.

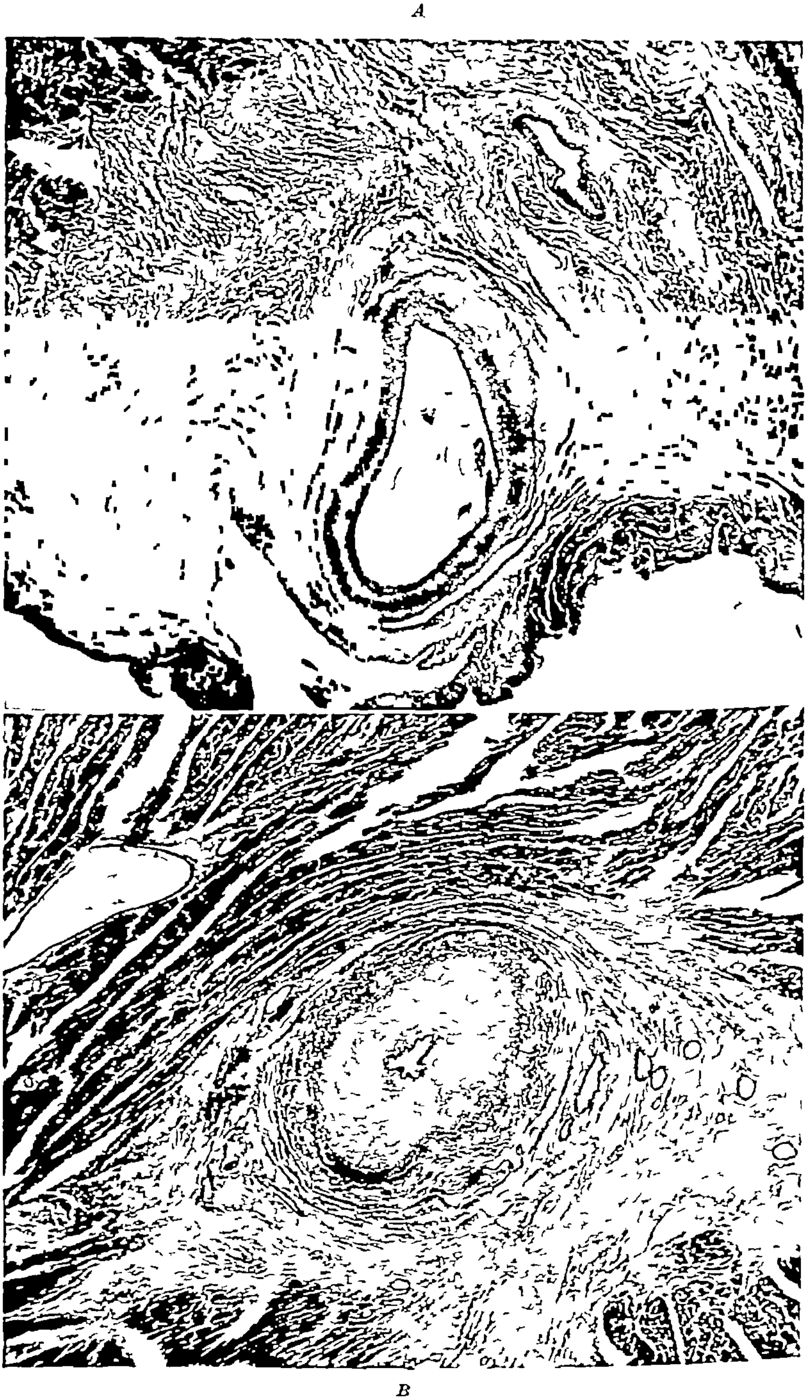

Fig. 7.—Serial sections taken through site of implantation of an internal mammary artery placed in a normal heart four months previously. *A*, Serial section proximal to open branches lying within the myocardium. There is some intimal proliferation. Actual lumen is 70 per cent of potential, and measures 1.2 by 0.5 mm. *B*, Serial section of same vessel distal to open branches. Lumen has been reduced to 10 per cent of its potential size.

The sections in Fig. 8 *A* and *B* were taken from a 58-week-old implant left in a normal heart. Fig. 8 *A* shows a section taken just proximal to the branching of the internal mammary artery. In this 58-week-old implant left in a normal heart intimal proliferation has developed proximal to the open branches, resulting in a markedly reduced lumen which amounted to 20 per cent of its potential. The actual measurements of this lumen were 0.5 by 0.42 mm. In Fig. 8 *B* taken through the artery beyond the open branches in the same animal the lumen is completely occluded. In these animals no attempt was made to promote myocardial ischemia. The implanted internal mammary arteries were in competition with normal coronary vessels. The pressure differential between the implanted internal mammary artery and the surrounding myocardial vessels was not great enough to maintain a rapid flow of blood through the implanted artery. The resultant intimal proliferation gradually diminished the size of or completely occluded the lumen. This process is very similar to that which occurs in other unused vessels in the human body such as the ductus arteriosus, etc.

ISCHEMIC HEART

Examination of serial sections taken through the internal mammary artery placed in an ischemic heart shows that the artery proximal to open branches is practically free of intimal proliferation. The intimal proliferation, however, is definitely present distal to open branches as is demonstrated by the sections shown in Fig. 9 which were taken four months after implantation and three months after ligation of the anterior descending branch.

The section in Fig. 9, *A* taken just proximal to branching, shows no intimal proliferation of the implanted vessel. Fig. 9, *B* shows the implanted artery distal to the branches. Note how the artery in this location has been almost completely occluded.

The size of the implanted internal mammary artery has been outlined by digestion casts in seven animals in which the internal mammary artery was forced to carry the load six weeks after implantation due to ligation of the anterior descending branch at this time. These arteries were then studied five, six and seven months after implantation. Fig. 10 outlines the size of the lumen of such an artery along with its branches seven months after implantation. It is clearly as large as a major coronary vessel. The amount of blood carried by this artery to an ischemic heart has been found to be 27.6 to 29 c.c. per minute. It is clear, assuming that the artery has not been damaged or angled, that the frequency and duration of anastomosis is related to the conditions of the soil into which the artery is *implanted*. In human cases of coronary artery insufficiency the soil theoretically should always be favorable when the artery is placed in muscle and away from a scar. It is interesting to note that of 9 human patients who have died following internal mammary artery implantation 7 died ten hours to ten days after operation, 6 had open arteries. That is a rate of 85.7 per cent which is approximately the percentage of coronary anastomoses that have occurred in animals. The one artery which was thrombosed was badly angled due to a marked elevation of the left diaphragm caused by paralytic ileus.

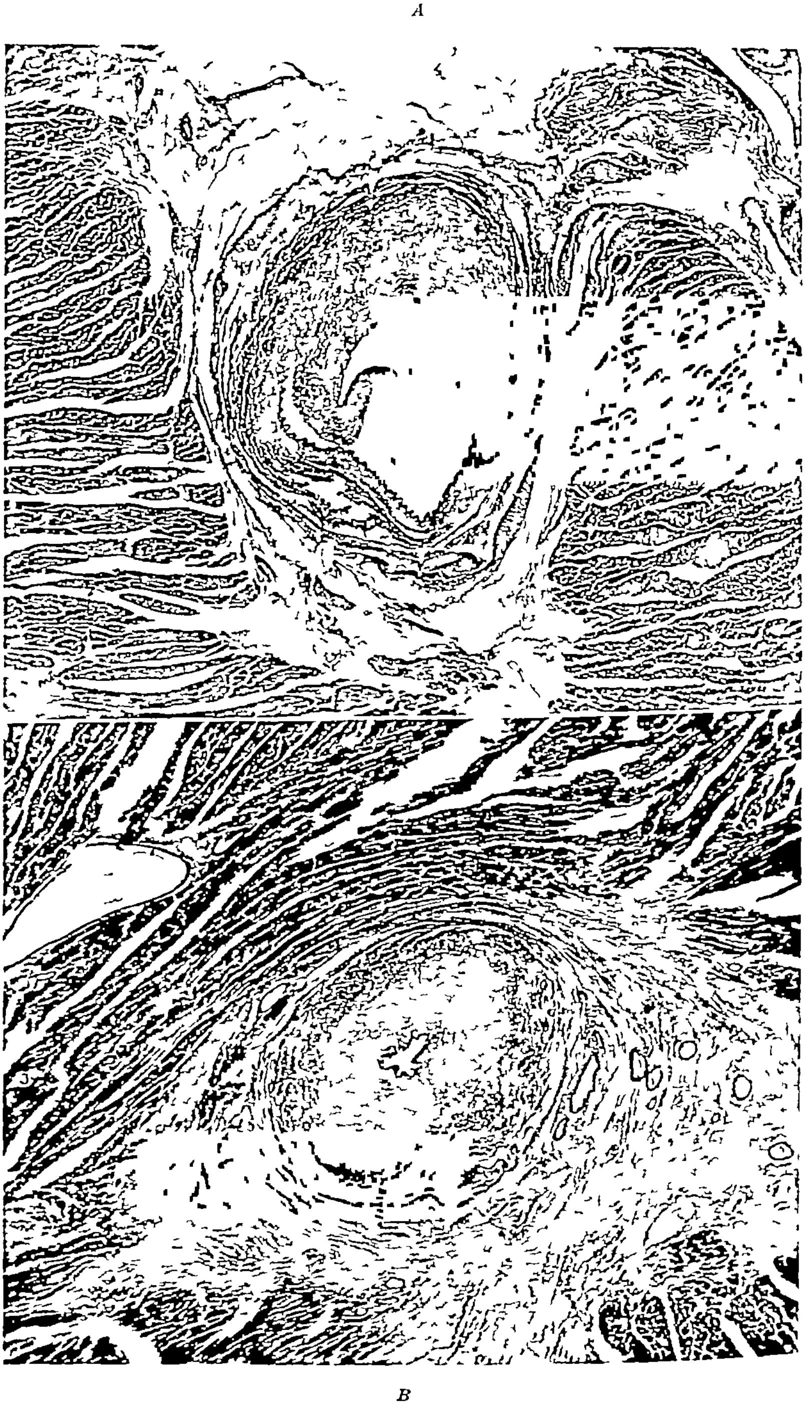

Fig. 8.—Serial sections taken through site of internal mammary artery implant placed in a normal heart for fifty-eight weeks. *A*, Serial section proximal to open branches. Note how intimal proliferation has greatly reduced the lumen of the vessel. *B*, Serial section of the same vessel distal to open branches showing the lumen practically obliterated.

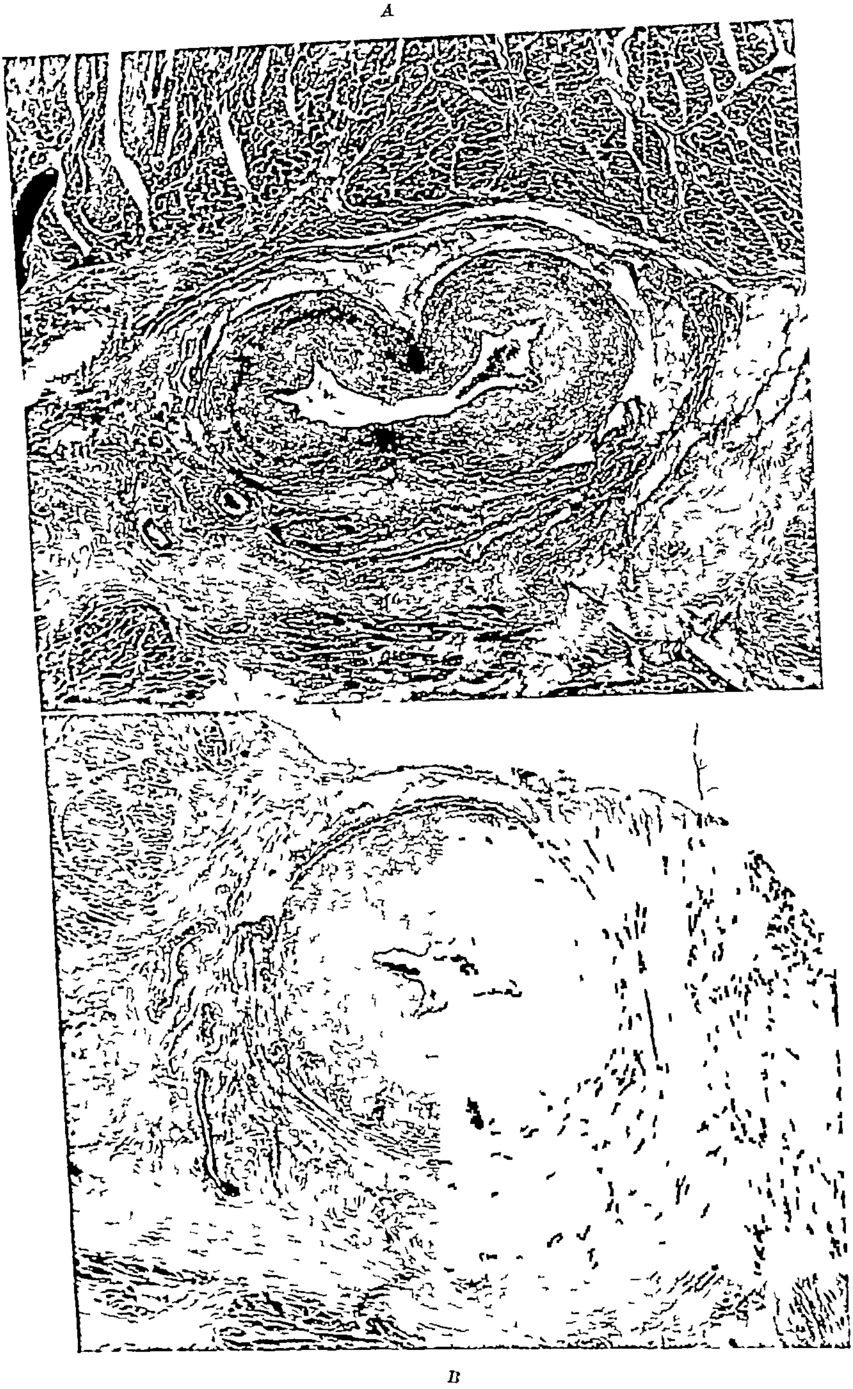

Fig 9—Serial section studies of internal mammary artery placed in ischemic heart in animal No 102 Sections were taken four months after implantation and three months after ligation of anterior descending branch *A* Serial section taken just proximal to branching of the artery within the myocardium There is no or little intimal proliferation at the end of four months *B* Same vessel distal to branches which join up with coronary vessels No marked proliferation with decrease in size of lumen

At present, as in the past, we are striving to increase the mammary coronary anastomosis rate.

At the suggestion of Sir James Learmonth, we have transected the left subclavian artery distal to the internal mammary artery. It is implanted into the left ventricle with many slits in its sides, from which blood pours into the myocardial tunnel. The value of this modification of the implant procedure is not yet established and, therefore, has not been used in the treatment of human cases of coronary artery disease.

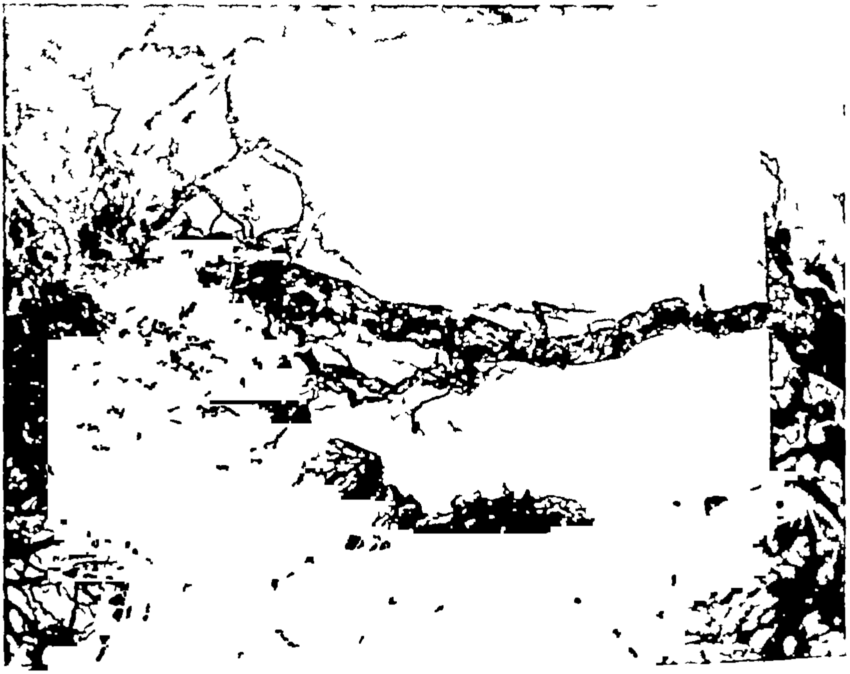

Fig. 10.—Digestion cast made by injecting the implanted internal mammary artery seven months after implantation and five months after ligation of anterior descending branch. Flow rates through this artery into the arterioles of the ventricle were 27.6 to 29 c.c. per minute.

RESULTS

Mortality.—A total of 45 patients suffering from coronary artery insufficiency have been treated by internal mammary artery implantation. In the 33 patients who had no angina at rest, there were 2 deaths, a mortality rate of 6.6 per cent. In the 12 patients suffering from angina decubitus, there have been 7 deaths, a mortality rate of 58.3 per cent. The mortality rate of the entire group was 20 per cent (Table II).

TABLE II. SUMMARY OF MORTALITY RATE IN 45 PATIENTS WITH CORONARY ARTERY INSUFFICIENCY TREATED BY INTERNAL MAMMARY ARTERY IMPLANTATION

	NO. OF PATIENTS	DEATHS	MORTALITY RATE (PER CENT)
No angina at rest	33	2	6.6
Angina decubitus	12	7	58.3
Entire group	45	9	20

Deaths Occurring Before Operation (Table III).—It is interesting to compare the operative mortality with the mortality rate occurring before operation. We have had 3 patients die in the hospital and 4 outside the hospital while awaiting operation. A total of 7 patients died awaiting operation; there was a total of 9 operative deaths. Almost as many patients have died awaiting operation as have died postoperatively.

TABLE III. DEATHS OCCURRING BEFORE OPERATION

Three patients have died in hospital from acute coronary occlusion and infarction while awaiting operation	
Four patients have died suddenly outside hospital while awaiting admission for operation	
Total deaths awaiting operation	7
Total operative deaths out of 45 cases	9
Almost as many patients have died awaiting operation as have died postoperatively	

PREOPERATIVE CONDITION OF FORTY-FIVE PATIENTS WITH CORONARY ARTERY INSUFFICIENCY TREATED BY INTERNAL MAMMARY ARTERY IMPLANTATION

Results.—An analysis of the condition of 45 patients prior to operation has been made. Table IV shows that 78 per cent were not working and that the other 22 per cent were working and using nitroglycerine. Fifty-six per cent could walk no more than 200 feet, and 44 per cent showed an average of seventeen steps on the two step test. Fifty-three per cent of the patients showed dyspnea and 53 per cent showed marked fatigue. Eighty-four per cent had had one or more infarctions.

TABLE IV. CONDITION OF 45 PATIENTS WITH CORONARY ARTERY INSUFFICIENCY TREATED BY INTERNAL MAMMARY ARTERY IMPLANT

Not working		34	(78%)
1 to 4 years	22		
1 to 11 months	12		
Working (with nitroglycerine)		11	(22%)
1 to 300 tablets weekly			
Exercise tolerance			
0 to 200 feet		25	(56%)
Two step (average, 17 steps)		20	(44%)
Dyspnea		24	(53%)
Orthopnea		2	
Marked fatigue		24	(53%)
One or more previous infarctions proved		38	(84%)

Forty Cases of Human Coronary Artery Disease Followed Six Months to Four and One-half Years.—The results of 40 human cases with advanced coronary artery insufficiency, treated by internal mammary artery implantation and followed from six months to four and one-half years since operation, are shown in Table V.

There were 30 patients who had no angina at rest. Of this number, 23 (77 per cent) were totally disabled prior to operation. Twenty-eight survived the operation and 16 (57.2 per cent) had no pain or slight pain. In 4 (14.2 per cent) the pain was less. Those with no pain or slight pain totaled 20 (71.4 per cent of the group). There were 7 patients who were the same or worse. Twenty-three (77 per cent) of the group returned to work after operation. This is a complete reversal of their condition before operation.

TABLE V. RESULTS OF CORONARY ARTERY INSUFFICIENCY TREATED BY INTERNAL MAMMARY ARTERY IMPLANTATION IN 40 PATIENTS FOLLOWED SIX MONTHS TO FOUR AND ONE-HALF YEARS

	BEFORE OPERATION			AFTER OPERATION			
	NO. OF PATIENTS	TOTALLY DISABLED	SURVIVED	NO PAIN OR SLIGHT PAIN	LESS PAIN	SAME OR WORSE	RETURNED TO WORK
No angina at rest	30	23 (77%)	28 (93.3%)	16 (57.2%)	4 (14.2%)	7 (25%)	23 (77%)
				71.4%			
Angina decubitus	10	10 (100%)	5	1	3	1	3

Four patients with no angina at rest have died months to years after operation.

Twenty-four (85.7%) of this group are still alive. Eighteen (64.2%) have no pain or less pain. Nineteen (67.8%) still work.

No change in the angina decubitus group.

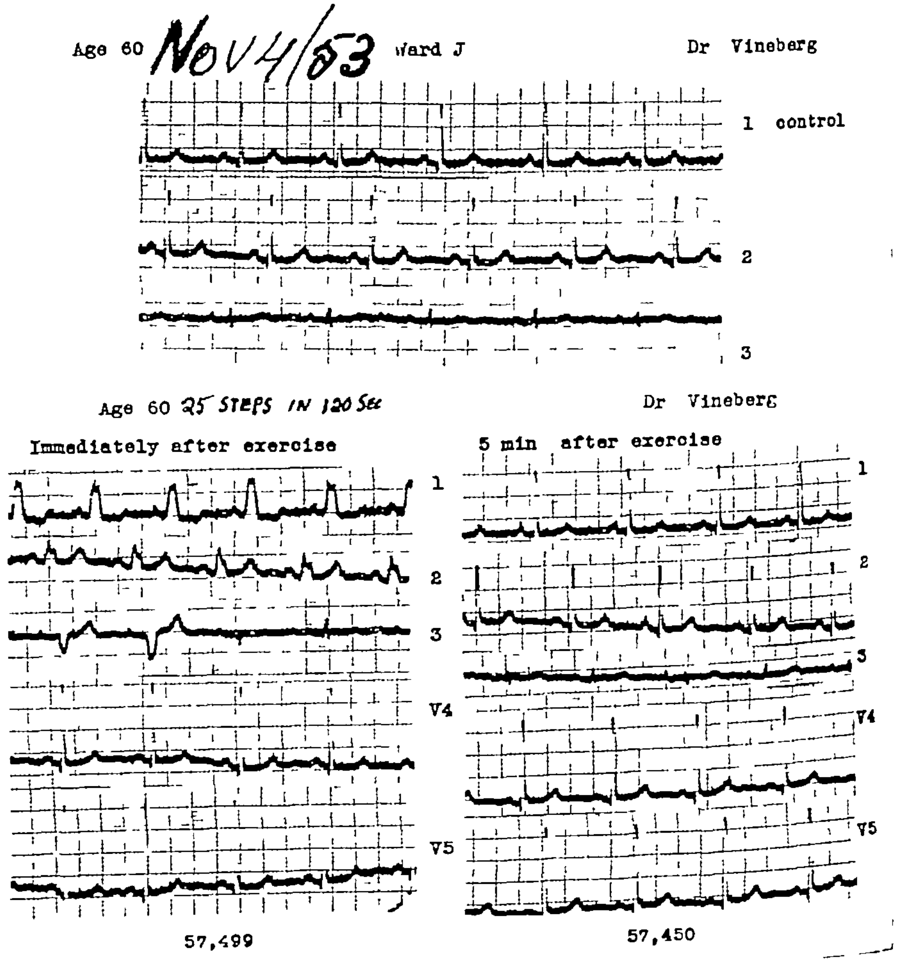

Fig. 11A.—Electrocardiogram of a 60-year old woman whose exercise tolerance on Nov. 4, 1953 was twenty-five steps in 120 seconds before the development of pain, dyspnea and left ventricular bundle branch block.

Your attention is drawn again to the fact that 23 (77 per cent) were totally disabled prior to operation, and 23 (77 per cent) returned to work after operation

There have been 4 late deaths in the no angina at rest group months to years after operation The causes are listed in Table VI

Twenty-four patients (85.7 per cent) of the group are still alive and 18 (64.2 per cent) have no pain or less pain while 19 (67.8 per cent) still work

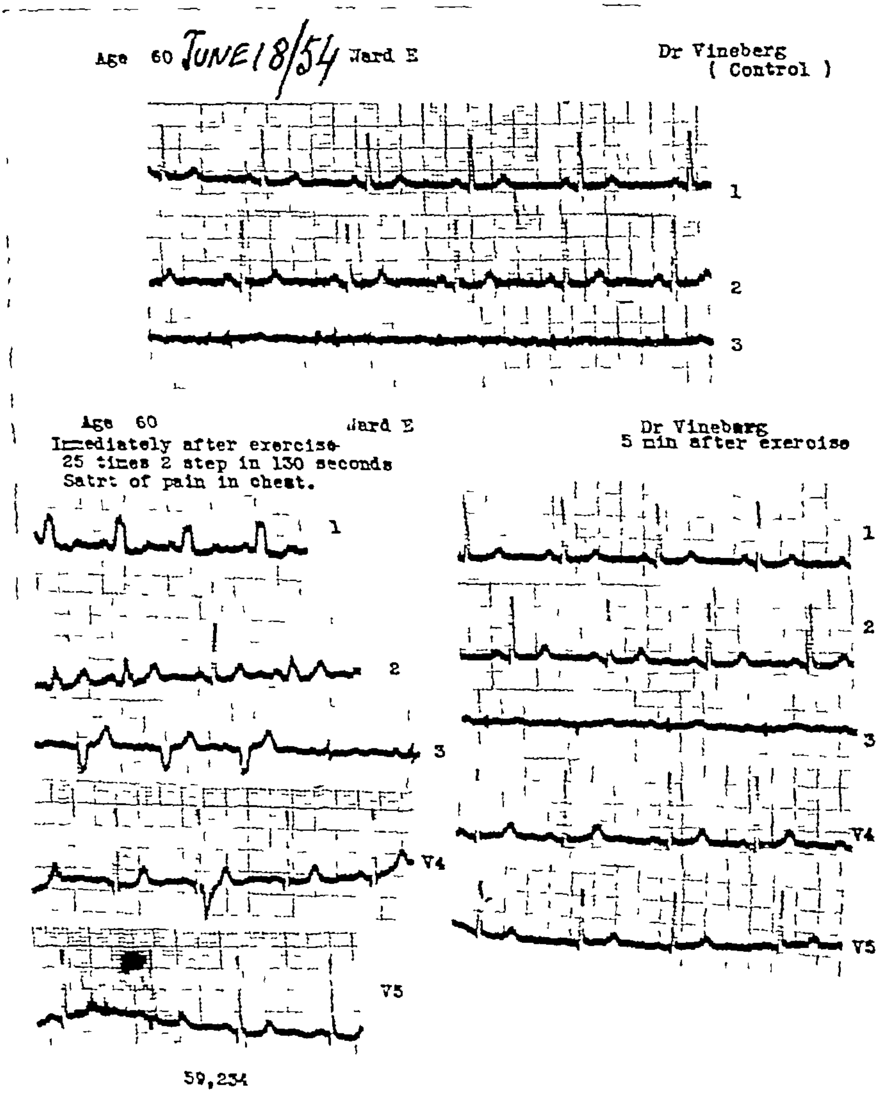

Fig. 11B.—Electrocardiogram of same patient as in Fig 11A whose exercise tolerance on June 18, 1954 was twenty five steps in 130 seconds before development of pain dyspnea and left ventricular bundle branch block.

TABLE VI CAUSES OF LATE DEATHS FOLLOWING INTERNAL MAMMARY ARTERY IMPLANTATION IN 45 CASES OF CORONARY ARTERY INSUFFICIENCY

One case (third patient) had steady increase in pain, Died four years postoperatively of aplastic anemia (artery had pulled out of heart)
One case, totally incapacitated preoperatively, worked one and one half years, died from rupture of old heart scar while pushing car out of snow
One case, totally incapacitated preoperatively, ran a cattle ranch for two years, died three years postoperatively after riding horseback
One case, error in diagnosis Large anterior scar, right ventricle, left ventricle normal, artery placed in left ventricle, no improvement, steadily worse, died six months postoperatively

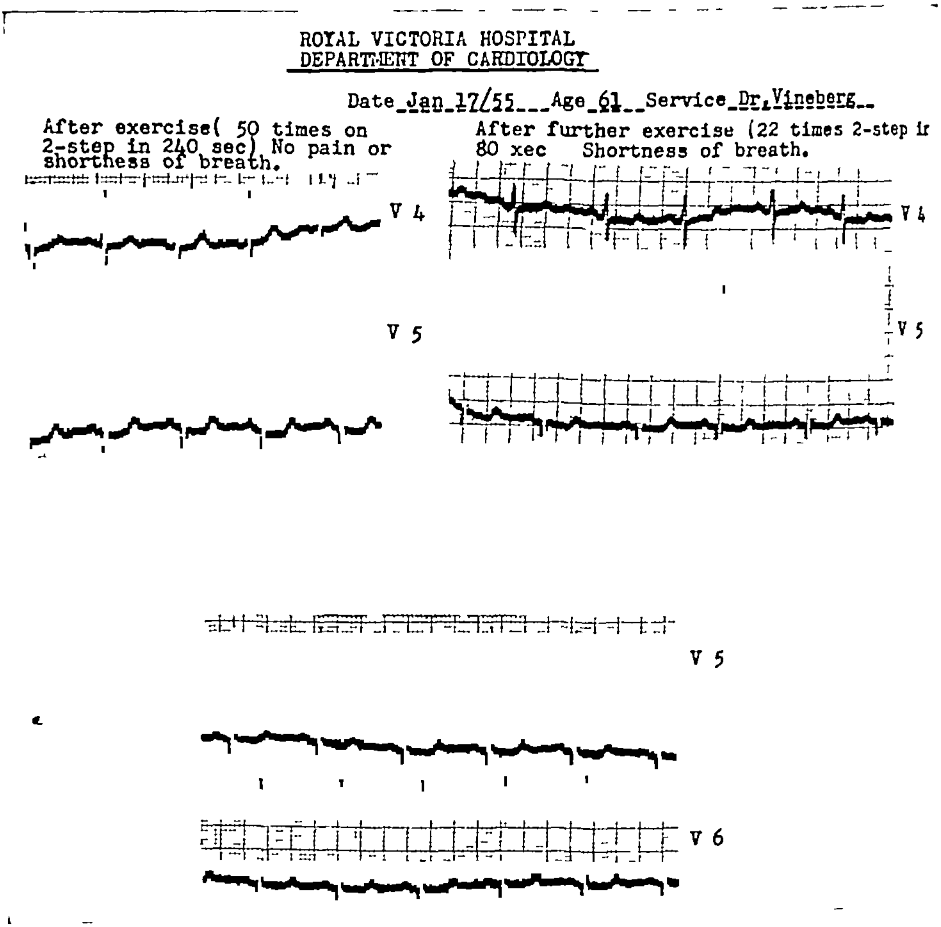
ROYAL VICTORIA HOSPITAL
DEPARTMENT OF CARDIOLOGY
Date_Jan_17/55___Age_61__Service_Dr.Vineberg__
After exercise(50 times on 2-step in 240 sec) No pain or shortness of breath.
After further exercise (22 times 2-step in 80 xec Shortness of breath.
V 4
V 4
V 5
V 5
V 5
V 6

Fig 12.—Electrocardiogram of patient in Fig 11 six months after internal mammary artery implantation Patient is free of pain and dyspnea Note tremendous increase in exercise tolerance without the development of pain or left ventricular bundle branch block.

In the angina decubitus group there were 12 patients, all totally disabled Five survived operation, 4 are improved, and 3 have returned to work

Our results in the treatment of coronary artery insufficiency by internal mammary artery implant are as you can see, most encouraging Before concluding, we should like to present a rather typical case

Mrs M. G, aged 60 years, was first admitted to the Royal Victoria Hospital because of severe angina in November, 1953 Her exercise tolerance was limited to twenty five steps in 120 seconds before she developed pain and dyspnea Electrocardiograms taken at the height of the pain showed left ventricular bundle branch block. There had been a history of peripheral edema and, because of the dyspnea, our medical group preferred not to subject her to operation In June 1954, this patient had to stop working because of her inability to walk one half block She was readmitted to the hospital where a second exercise tolerance test showed, once again, a limit of twenty five steps before the onset of pain and dyspnea Again, the left ventricular bundle branch block was shown on the ECG at the height of pain (Fig 11) In July, 1954, she received an internal mammary artery implant, and returned to work in September, 1954, free of pain and with a markedly increased exercise tolerance The dyspnea had disappeared

On Jan. 17, 1955, this patient was re exercised and after fifty steps in 240 seconds there were no pain, no dyspnea, no increase in heart rate, and—more important—no evidence of left ventricular bundle branch block! Because the pulse rate had not gone up she was immediately re exercised at a faster pace After twenty two steps in eighty seconds, she developed slight dyspnea There were, however, no pain and no evidence of left ventricular bundle branch block (Fig 12)

It is our opinion that there is some objective evidence of improvement in this case!

SUMMARY

The technique of internal mammary artery implant is given and some of the factors which favor mammary-coronary anastomosis are discussed

Evidence has been presented to show that the frequency of mammary-coronary anastomosis is dependent upon (1) technique of the preparation of the artery (2) technique of implantation, and (3) the condition of the myocardium into which it is implanted The duration of the anastomosis is dependent upon the need for it When the internal mammary artery is placed in ischemic animal hearts there is a mammary-coronary anastomosis rate of 71 per cent In 7 human cases examined ten hours to ten days after implant, the artery was found to be open in 71 per cent

Intimal proliferation occurs to a slight extent in all implanted internal mammary arteries This however increases when the blood flow through the artery is slowed Thus in the same implant intimal proliferation may be absent proximal to open branches and very marked distal to them

When an artery is placed in an ischemic heart, there is practically no intimal proliferation proximal to open branches

The mortality rate of 45 patients treated by implant is given and the results in 40 patients followed six months to four and one-half years are presented The results in the treatment of human cases of coronary heart disease are very satisfactory Seventy eight per cent of the group were not working prior to surgery and 77 per cent have returned to work

The patients referred to have been operated upon at the Royal Victoria Hospital, Jewish General Hospital Queen Mary Veterans' Hospital and the Institute of Cardiology, all of Montreal

We wish to express our appreciation for the assistance of Drs G Lyman Duff and G C McMillan of the Department of Pathology, Royal Victoria Hospital, and Dr Rene Mailloux, of the Institute of Cardiology, Montreal

DISCUSSION

(PAPERS BY LEIGHNINGER, AND VINEBERG AND BULLER)

DR. FREDERICK R. MAUTZ, Cleveland, Ohio.—The crucial proof of the success of a procedure designed to increase collateral blood flow to an ischemic segment of myocardium would seem to be the actual demonstration and measurement of increased blood into the area under physiologic conditions approaching the normal. In 1941, Beck and associates, in carefully controlled experiments, showed that abrasion of the heart one to three weeks prior to descending ramus coronary artery ligation reduced the mortality from a well established control value of 70 per cent to 38 per cent, and appeared to reduce the degree of infarction in the survivors. Critics raised the question as to whether factors other than improved circulation might be responsible for these results.

In 1937, Gregg and I postulated that the events taking place within an occluded coronary artery should give the best indication of the development of collateral circulation and also provide a means of determining the exact sources of the blood. At that time we were able to demonstrate the spontaneous development of collateral circulation following occlusion of coronary arteries, both by acute ligation and by progressive partial occlusion in stages. It was thought that this would serve as a base line for the study of procedures designed to augment the spontaneous development of collateral. The amount of collateral that developed varied greatly from little or none in some instances to what might be termed a massive collateral in other instances. The amount of collateral flow seemed to vary inversely with the degree of infarction. In these instances the primary stimulus to the development of collateral appeared to be arterial obstruction with resultant hypoxia of an area of myocardium. No effort was made to augment the development of the collateral, although the effect of surgical exposure of the heart for the purpose of occluding the coronary arteries remained as a factor to be evaluated.

In trying to establish the source of the collateral, two thirds or more could be definitely shown to come from the unoccluded coronary arteries. We did not succeed in tracing the source of one tenth to one third of the collateral, except that the quality of the blood was indistinguishable from arterial blood on the basis of oxygen and carbon dioxide content. Some of it, no doubt, came from the septal artery and the remainder from basal extracoronary anastomoses. These findings were in agreement with the anatomic observations presented to this Association in 1937, namely, that by far the greatest increase in size of collateral channels was in the intercoronary anastomoses.

The importance of Dr. Leighninger's work rests upon the fact that he has shown, by retrograde blood flow studies, that factors other than coronary arterial obstruction will significantly increase basic arterial collateral flow, namely, abrasion of the epicardium, chemical irritation of the epicardium, and partial coronary sinus obstructon. This work beautifully complements the tests of benefit previously used by Beck and associates, namely, (1) reduction in mortality and (2) size of infarct. Dr. Leighninger's work clearly invalidates any hypothesis that the beneficial effects of these procedures are fortuitous or are the result of factors other than improved collateral circulation.

We can now say without reservation that the studies presented by Dr. Leighninger provide the crucial proof, which our medical colleagues have so long demanded, that collateral arterial flow to the myocardium can be increased by surgical methods in term of actually measured blood flow under normal circulatory conditions.

DR. ALFRED GOLDMAN, Beverly Hills, Calif.—(Slide) I wish to show another method for augmenting coronary circulation which we have been studying experimentally in dogs. This method involves the transplantation of a U-shaped arterial graft obliquely through the myocardium so that the multiple openings in the graft simulate the thebesian sinusoidal luminal system and coronary blood from the left ventricular cavity to its myocardium.

(Slide) This is a method of evaluating the size of the infarcts when the dogs are challenged after being prepared two months previously with the grafts Challenge consists of ligation of the anterior descending coronary artery

(Slide) This is the method developed by Dr Sherman Strauss for measuring the two diameters of the infarcts Here are the sections from which the diameters are measured The slices at right angles to the anterior descending coronary artery are 2 to 3 mm thick. The third dimension, or N number is estimated from the character and extent of the infarcted myocardial thickness When the diameters of the infarcted area are compared with the diameters of the heart itself and infarct ratio is computed and the IR index is multiplied by the N number a numerical value for the infarct size is obtained. In our present preliminary stage the infarct size is represented by the numerical value and has not been found to be significantly decreased.

(Slide) Here is the microphotograph of the graft in situ showing the lumen of the blood vessels parallel with the graft

(Movie) *A colored motion* picture showing another method of electrocardiographic exploration of the human ischemic heart was shown Dr Myron Prinzmetal has been in charge of the electrocardiographic interpretation.

DR T H. WALKER, Charleston W Va —I would like to record my experience with the Vineberg procedure Twenty four patients have been operated upon for coronary insufficiency following myocardial infarction There has been one fatality and this was prior to placing the artery in the myocardium There are 23 living patients One patient still requires nitroglycerine but in much smaller quantities three patients are too recent for follow up one has minimal congestive failure 18 have had good results In some of the 23 living patients I have modified the procedure somewhat in that talcum powder poudrage has been used as advocated by Dr Thompson along with the internal mammary artery transplant I cannot see any definite difference between the procedure as done primarily by Dr Vineberg or with the addition of poudrage

DR T D FRYFOGLE Detroit Mich —I stand in awe and appreciation of the wonderful work of Drs Beck and Leighninger This stimulated me in 1952, to perform my first Beck II procedure The patient did so well after being a cardiac invalid, that he now makes all our cardiac instruments There is no question, I think that at least for the first ninety days *the formation* of intercoronary channels resulting from a free vein graft or direct arterialization of the coronary sinuses does occur Speaking in terms of thrombosis which has plagued Drs Vineberg and Beck for awhile with the vein graft, and thinking also of the patient s trepidation about a second operation after arterialization I sought in our own little laboratory to arrive at a means whereby we could accomplish the same end with a single operative procedure I would like to show the technique of this

(Slide) This will orient you with the typical Beck procedure, with the free vein graft coming between the aorta and the coronary sinus

(Slide) You do the first part of this operation (here is the coronary sinus and here is the free vein graft) Then you take the small gunlike instrument as pictured. To it is attached a siliconized polythene plastic cuff The idea of obtaining arterial blood from the ventricular cavity originated with Dr Thomas O'Neill of Philadelphia This piece of polythene plastic is excellent for the procedure it fits directly over the sleeve of the punch and it has an imbedded silk suture in its neck There are two little special needles curved on the end You advance the instrument through a sleeve as demonstrated

(Slide) There is a simple purse-string suture around the sleeve which controls bleeding. You push the instrument through the ventricular wall and are able to punch out with a single motion a nice round hole The secondary sleeve pushes the plastic prosthesis into the cardiac wall This has not been *done on* any human patients, but it has been done on 23 dogs The coronary sinus is never in the same place, sometimes it is up in the auricle wall, sometimes down in the ventricle wall, and sometimes right over the valve itself By placing the finger through the auricular appendage, you can direct exactly where in the heart wall you want to place the prosthesis

(Slide) Then you place the plastic prosthesis where you want it, sew it into the myocardium, and tie outside the wall You are now ready to close the graft sleeve and cut off the excess

This is an easy operation to do and it accomplishes a free flow of blood from the left ventricular cavity It allows two things that I think are important in preventing thrombosis First, you do not distort, in any way, the coronary sinus Second, you are able to tie down the sinus to 3 mm at the time of operation and do not get rupture of the little venules over the heart wall, as you do when you are obstructing aortic pressure In the aorta you have systolic pressure and diastolic pressure, and I think that the constant diastolic pressure is the factor that makes the small venules rupture When you have direct communication to the left ventricular cavity you have a systolic pressure, true, which permeates the heart wall, but a zero diastolic pressure, thus allowing the vein to rest This, I think, is the reason we do not get rupture of the small peripheral veins Six of the 23 dogs have been kept for duration studies These will be reported in subsequent writings and I ask that this be accepted as a preliminary report

DR J L EHRENHAFT, Iowa City, Iowa —Ever since seeing Dr Vineberg's work in Montreal last year, we have been very much impressed by the possibility of creating a third coronary artery by vessel implantation into the myocardium Recently we have used the splenic artery in dogs for myocardial implantation This vessel is quite long and can easily be brought up from the abdomen through the diaphagm Obviously, this is only an experimental procedure that is possible in dogs because the spleen and splenic arteries in this animal are very easily mobilized. I doubt very much that this vessel could be used in the human patient We have found that those vessels, after implantation, seem to remain patent and probably form anastomoses with the other coronary vessels

DR DAVID S LEIGHNINGER, Cleveland, Ohio (Closing) —I would like only to thank the discussors

DR VINEBERG (Closing) —I wish to take this opportunity to congratulate Dr Leighninger, whose work I have been following with much interest for a number of years

I have had no definite experience with the Mautz and Gregg method of studying intercoronary arterial communication In our laboratory, many types of revascularization procedures have been tried, which include attempts at making artificial thebesian canals, cardio omentopexies, pericardial fat grafts, coronary vein ligation, and talc and implant procedures In 55 animals, where there has been no evidence of revascularization, animals died in 83 1 per cent of the cases when the anterior descending branch of the left coronary artery was ligated In 40 animals, in which there was revascularization due to adequate mammary coronary anastomoses, there were no deaths

In the first group of 55 animals, in which various types of operations designed to promote revascularization failed to do so, the operative interference in itself did not protect these animals against anterior descending branch ligation

Because of this information, I cannot agree with Dr Beck and his associates, who have indicated that, no matter what is done to a heart, the procedure in itself promotes the development of collaterals This statement may be true in part, but certainly, in our experience with animals, these collaterals were not functioning six weeks to two months after unsuccessful attempts at revascularization in normal animals' hearts by different types of revascularization procedures

The coronary arteriolar tree is divided into three separate and distinct zones (Fig 1) These zones in the normal heart usually have no communication When coronary artery disease intervenes, or ischemia of the heart is promoted through other means, communications between these separate arteriolar zones develop and, in this way, collateral vessels are formed (Fig 2) It seems to us that this is the only time that the term "collateral" should be used in reference to coronary artery disease Since coronary disease usually involves the epicardial portions of the major vessels, it is very difficult to conceive how the development of collaterals between three separate arteriolar zones can bring fresh blood past the blockage which occurs in the proximal portion of the major coronary arteries

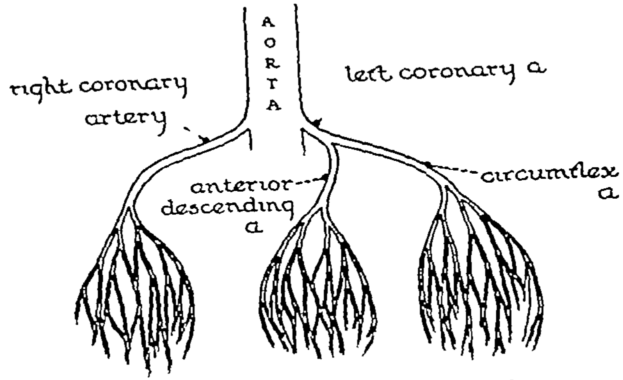

Fig 1 —Arteriolar zones (normal heart) Three distinct arteriolar zones normally no connections between zones no collaterals

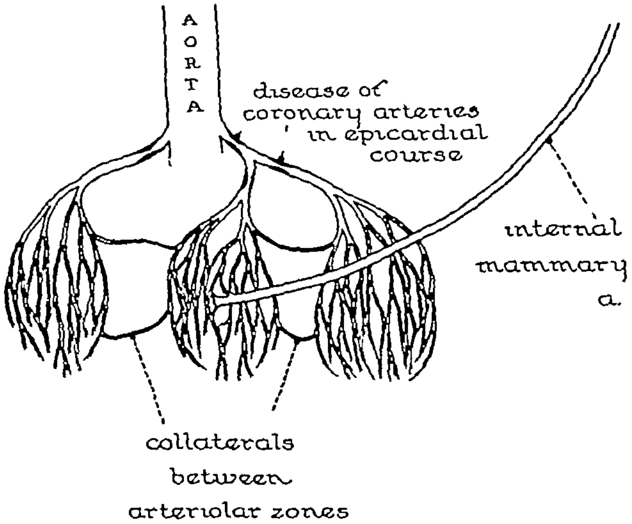
AORTA
disease of coronary arteries in epicardial course
internal mammary a.
collaterals between arteriolar zones

Fig 2 —Arteriolar zones (ischemic diseased heart)

The methods which aim at stimulating the development of intercoronary or collateral circulation, such as have been described by Beck and associates, in our opinion are bound to fail, because what they attempt to do has already been done by Nature It has been shown by many pathologists, including Schlesinger, Zoll, and Blumgart, that 98 per cent of human cases of coronary artery insufficiency develop extensive collateral pathways between the various arteriolar zones Therefore, operations on human cases of coronary artery insufficiency that are designed to promote collateral circulation would appear to be unnecessary, in so far as that which they are supposed to do has already been done What is necessary in coronary artery insufficiency is a powerful new source of extracardiac blood which is brought to the ischemic myocardium in such a manner as to bypass the occluded proximal portions of the major coronary vessels *

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*References Schlesinger M J An Injection Plus Dissection Study of Coronary Artery Occlusions and Anastomosis Am Heart J 15 528 568 1938 Schlesinger M J Relation of Anatomic Pattern to Pathologic Conditions of Coronary Arteries Arch Path 30 403 415 1940 Zoll P M Normal and Pathological Anatomy of the Coronaries Tr Am Coll Cardiology 1 29 1951

AN ANALYSIS OF FIFTY PATIENTS TREATED BY MITRAL COMMISSUROTOMY FIVE OR MORE YEARS AGO

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O HENRY JANTON, M D (BY INVITATION)
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INTRACARDIAC surgery for certain types of congenital and acquired diseases is now a well-established and highly successful adjunctive and definitive form of treatment The mitral valve, the commonest site of intracardiac pathology, has naturally occupied the center of attention during these developmental years, for the relief of its obstructive effects marked the initial phase of this rapidly growing field Whereas commissurotomy for mitral stenosis was performed with hesitancy and reticence in 1948 and 1949,[1, 2] this operation is now regarded by physician and surgeon alike as a routine procedure, the model for acquired valvular surgery As its performance has become more universally applied, increasing numbers of physicians now have a personal experience with the problems which these patients present A natural concern has developed as to the ultimate outcome of patients so treated Many physicians have witnessed the dramatic and almost unbelievable results of this surgery in patients for whom there seemed no possible medical hope On the other hand, these same physicians have encountered a number of patients who have not responded to the same degree and, by focusing their attention on these, have found their initial enthusiasm favorable but somewhat dampened

A second but infinitely smaller group of internists have steadfastly refused to believe the reports of patients who describe their improvement in glowing terms primarily because, in many instances, they cannot substantiate this functional improvement by objective means Therefore, in an attempt to clarify this state of confusion, it seemed imperative to review exhaustively a representative number of patients consecutively treated by commissurotomy five or more years ago, this span of time representing the longest available period of observation The purpose of this communication then is to present in a detailed and painfully statistical manner all available data concerning fifty such patients, the first of whom was operated upon in January of 1949 It must be stated in advance, however, that more than average difficulty was encountered in obtaining all the information considered essential for this analysis because these patients live in many parts of the country Nevertheless, over half the patients have been examined personally (O H J and R P G) within the past two months and complete information including electrocardiographic tracings and teleoroentgenograms has been obtained from

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both patients and attending physicians in the remainder during the same period To ensure a completely uniform method of reporting operative findings all patients in this series have been operated upon by a single surgeon (R P G)

ANALYSIS OF PATIENTS

Fifty-one patients were subjected to surgery five or more years ago The first of these is now six and one-half years postoperative One patient in the series was followed for the first two postoperative years only and at that time her condition was excellent asymptomatic without medication She has been deleted from this study for her present status and whereabouts are unknown Of the remaining fifty thirty-six were women and fourteen were men. The average age at the time of surgery was 34 years

Status Prior to Admission—There was a definite history of rheumatic infection in twenty (40 per cent) of these patients Each of the fifty patients was suffering from some degree of functional incapacity There was a history of gross hemoptysis in twenty-three patients (46 per cent) Twenty-seven patients (54 per cent) had suffered one or more bouts of congestive failure In six (12 per cent), arterial emboli had occurred from which a reasonable recovery had been made

Admission Findings—When admitted for preoperative and operative treatment to our hospital services, thirteen (26 per cent)of these patients were in gross chronic congestive heart failure Nineteen (38 per cent) were in permanent atrial fibrillation

Preoperative Classification of Patients—As the mere presence of a mitral diastolic murmur in an asymptomatic patient was not then and is not now an indication for mitral commissurotomy none of these patients was in Stage I (murmur without symptoms) Five patients (10 per cent) were suffering from fatigue and exertional dyspnea but as these symptoms had not progressed materially in the preceding year they were classified as Stage II (statically incapacitated) In thirty six patients (72 per cent), in spite of continuous and vigorous medical management a progressively downhill course was apparent (Stage III, progressively incapacitating) The remaining nine patients (18 per cent) showed constant evidence of congestive failure and as such were classified as Stage IV Each of these patients was subjected to the standard mitral commissurotomy as described in previous publications[2-4] (Table I)

TABLE I. FUNCTIONAL CLASSIFICATION
(41 Living Patients)

PREOPERATIVE		POSTOPERATIVE			
Stages		I	II	III	IV
One	(0)	0	0	0	0
Two	(5)	2	3	0	0
Three	(29)	11	11	6	1
Four	(7)	1	4	1	1
Total	(41)	14	18	7	2

Key Written numbers designate preoperative functional status Roman numerals designate postoperative functional status Numbers in parentheses designate total number of patients per stage classified preoperatively

Mortality—Three patients died within the first postoperative month, representing an operative mortality of 6 per cent Each of these was an advanced Stage III problem and each was in atrial fibrillation

The first died suddenly from acute cardiac decompensation (the day before his proposed hospital discharge) Post-mortem examination revealed a moderately calcified valve of very limited pliability The previous mitral insufficiency had been considerably aggravated by the posteromedial commissurotomy which had been performed because there was no anterolateral commissure, the mitral orifice being eccentrically placed A moderately severe but previously undiagnosed aortic stenosis was noted The second patient died four weeks after surgery, following a stormy postoperative course complicated by slowly increasing congestive failure to the point of anasarca The valve had been opened by finger pressure alone which had caused an inadvertent tear of the posterior mitral cusp along its lateral attachment Death was therefore caused by the production of too much mitral insufficiency clearly verified by post-mortem examination This examination likewise revealed that the superior one-third of the left atrial lumen was completely obliterated by a thrombus the size of a lemon The third patient died two hours after surgery, from which he never responded His left atrium had been entered with difficulty through a completely obliterated appendage and the tiny valve orifice split by finger pressure alone Autopsy revealed that the commissurotomy had been performed properly in the anterolateral commissure without damage to either leaflet The cause of death was apparently due to operative and anesthetic shock Aortic valve disease of the insufficiency type was found to be present

Six additional patients died, one at six weeks, one at seven months, two at two and one half years, and two at three years following the performance of commissurotomy Three of these patients had been classified as Stage IV and three were in advanced Stage III All these patients had extensively calcified valves whose leaflets were thickened, fibrosed, and nonpliable The three Stage IV patients were in a terminal state at the time of surgery and their deaths are contributable to irreversible cardiopulmonary, hepatic, and renal disease In a fourth, a preexisting mitral insufficiency was aggravated by surgery and this patient went downhill slowly as is their wont The remaining two patients had completely inoperable valves due to marked calcification and unyielding induration precluding other than an inadequate commissurotomy By and large, it can be stated that the cardiovalvular status of each of these patients had advanced to such a degree of deformity that no surgical intervention could be expected to be of lasting value

Thus, there was an operative mortality of 6 per cent (three patients) and a late mortality within the first three postoperative years of 12 per cent (six patients) The remaining forty-one patients are living today, approximately five to six and one-half years postcommissurotomy and the data on these patients will comprise the remainder of this presentation

Present Classification of 41 Living Patients—(a) Each of the five patients originally classified as Stage II has lived a relatively normal life to date Two of these are completely asymptomatic and can now be classified in Stage

I, for some slight element of their original diastolic murmur remains. The three others have been (conservatively) left in Stage II, for at times they have experienced more fatigue than that which could be considered normal and on a few other occasions their exercise tolerance was less than that which we expect in a normal person. (b) Twenty-nine of the thirty-five patients originally classified as Stage III are living. Eleven of these are completely asymptomatic and have reverted to Stage I. Eleven additional patients have been placed in Stage II, and six remain in Stage III although they continue to be functionally improved over their preoperative state. The remaining patient in this group has now been classified in Stage IV, for some element of chronic congestive failure remains constant. (c) Quite surprisingly seven of the ten patients originally classified Stage IV are living. One is completely asymptomatic and is in Stage I, four have been reclassified as Stage II, one is in Stage III, and one remains in the original classification, Stage IV.

To recapitulate then, in the entire group of forty-one living patients there are now fourteen in Stage I, eighteen in Stage II, seven in Stage III, and two in Stage IV. It is readily apparent, therefore, that only one patient in the series is now classified at a higher level of incapacity than that prior to surgery. This rearrangement of the classification of these patients is purely didactic, was made by us, and is an attempt to evaluate patients purely within the limits provided by the original arbitrary stages as published in the past[5, 6] (Table I).

The Patient's Classification of His Own Present Status.—(a) On close and detailed interrogation of the patients themselves, confirmed by their home physicians, twenty of these forty-one patients (40 per cent of the original fifty cases) consider themselves to be in an excellent state of health. They deny symptoms during the course of all normal activity, although a few will admit to some minor limitations should they exert themselves considerably beyond their normal routine of life. These patients engage in such forms of exercise as golf, dancing, swimming, bicycle riding, and bowling. Eleven of them use no medication of any type, and are on a normal diet. Nine have continued to use digitalis sporadically. When questioned carefully on this point, their use of digitalis is in small dosage and on an average of every second or third day. By classification three of these patients were originally in Stage II, thirteen in Stage III, and four in Stage IV.

(b) Sixteen (32 per cent of the original fifty cases) consider themselves very definitely improved over their preoperative state. These patients feel that they are living a relatively normal life so long as they stay within certain self-imposed limitations which have been found by trial and error to be proper for them personally. Thirteen of these take a daily maintenance dose of digitalis but three require no cardiac medication. A few of these remain on a low salt diet to which they have long become accustomed, as they have stated, "I no longer have any desire for salt." Four use Diamox occasionally.

(c) Five of these forty-one living patients (10 per cent of the original fifty) regard themselves as unimproved over their preoperative state although each passed through a period of two to four years during which he was considerably improved. They have all rather profusely expressed gratitude for the surgery as performed and have stated, possibly euphorically, that without surgery they would not now be alive. By classification, four of these patients were Stage III and one in Stage IV prior to surgery.

To summarize and to compare these findings, the status of these forty-one living patients can be stated as follows: According to their present classification as rated by us, thirty patients (60 per cent of the entire group subjected to surgery) are better after five years than they were preceding surgery. According to the patients themselves, 72 per cent (thirty-six of the original fifty) are definitely better after five years than they were prior to surgery.

Analysis of Murmurs.—(a) Twenty-five of the forty-one living patients were considered on clinical auscultatory grounds to be cases of pure mitral stenosis. Seven of these now have no mitral diastolic murmur and three of these seven have no murmurs at all in any of the valve areas. Three others have a soft systolic mitral blowing murmur indicative of some insufficiency, and one has an additional soft diastolic murmur along the left sternal border suggestive of aortic insufficiency.

Eighteen of the twenty-five still have some degree of their original mitral diastolic murmur and ten of these have an additional systolic element that was not formerly present.

(b) Ten of the forty-one living patients originally had, in addition to their greatly predominant mitral diastolic murmurs, an element of mitral insufficiency as indicated by a systolic component to the murmur.[7] Six of these still have a measure of both diastolic and systolic murmurs. In three others the diastolic murmur has disappeared and is now replaced by a systolic murmur only. The one remaining patient has no detectable murmurs at this time.

(c) Four of the forty-one living patients originally had, in addition to their predominant mitral diastolic murmurs, a diastolic murmur along the left sternal border suggestive of aortic insufficiency. This was presumed to be of adynamic proportions, for no other clinical signs were present to substantiate a significant degree of aortic insufficiency. Each of these four cases still retains some measure of his mitral stenotic and aortic insufficiency murmurs. Two of these have obtained excellent functional results, one is markedly improved, and the other remains unimproved.

(d) One of the forty-one living patients originally had both a mitral systolic and diastolic murmur and an aortic diastolic murmur, and elements of all of these murmurs are still present although the patient is very definitely improved functionally. One additional patient of the forty-one living cases had systolic and diastolic murmurs both in the mitral and aortic areas and still has, but is likewise in an improved functional state.

To summarize the auscultatory findings in these patients, only four of these forty-one living patients have a completely murmurless heart at this time. Eleven have lost all evidence of a mitral diastolic murmur. Fourteen patients now have a systolic murmur at the apex in the mitral area of various degrees which they did not have prior to surgery.

From a functional standpoint those patients who had a pure murmur of mitral stenosis prior to surgery have had the best results. Fourteen of these twenty-five patients are now excellent, nine are improved, and two are unimproved. This result is a little better than that obtained in the ten patients who were predominantly mitral stenosis cases but who had an associated systolic component to the murmur prior to surgery. In this group four obtained an excellent result, four were improved, and two were unimproved.

Electrocardiographic Changes.—

Rhythm. There were twenty-nine patients in normal sinus rhythm at the time of surgery. Not infrequently atrial fibrillation appeared in this group during the early postoperative period, usually within the first four days. In nine of these incidences this arrythmia has remained to the present time, even though intensive quinidine therapy was carried out both during the hospital stay and on one or more occasions thereafter. All these patients, including those who are now in atrial fibrillation, have remained improved or excellent to the present time.

In the remaining twelve cases atrial fibrillation was present preoperatively and has remained constant to date. In this group five are unimproved over their preoperative state but the other seven maintain an improved to excellent status.

The P wave. In general, the P wave did not change either in its duration or configuration. Occasionally, the high voltage of the P wave, usually noted in cases with sustained and marked pulmonary artery hypertension, was reduced in amplitude after an adequate commissurotomy.

The QRS complex. There were ten cases in which, from the QRS standpoint, preoperative electrocardiogram was normal. This state remained essentially unchanged after commissurotomy except for slight counterclockwise rotation around the longitudinal axis.

The remaining thirty-one showed moderate to marked right ventricular hypertrophy. This pattern showed a variety of changes. In eleven a recession of the right ventricular hypertrophy pattern was observed and in seven of these it completely disappeared.

In ten cases Lead V_1 showed a delay in the activation time of 0.04 to 0.06 second. These alterations returned to normal within one to two years after commissurotomy and have remained so to the present time.

In the remaining ten cases there was no significant change in the right ventricular hypertrophy pattern except for slight evidence of a combined hypertrophy pattern in one. In this individual a dynamic mitral insufficiency is now present.

Roentgenographic Findings.—Since the inception of this surgical program the anticipated roentgenographic changes have always been the source of considerable speculation because of the graphic nature of this type of study.[5] It is frequently rather difficult to evaluate the observed changes in cardiac size due to the many postoperative variables such as pleural reaction, pericardial reaction and adhesions, changes in the patient's weight, and the variations in x-ray techniques which occur even in the same institution at different times. Despite these difficulties the following statements can be made with confidence.

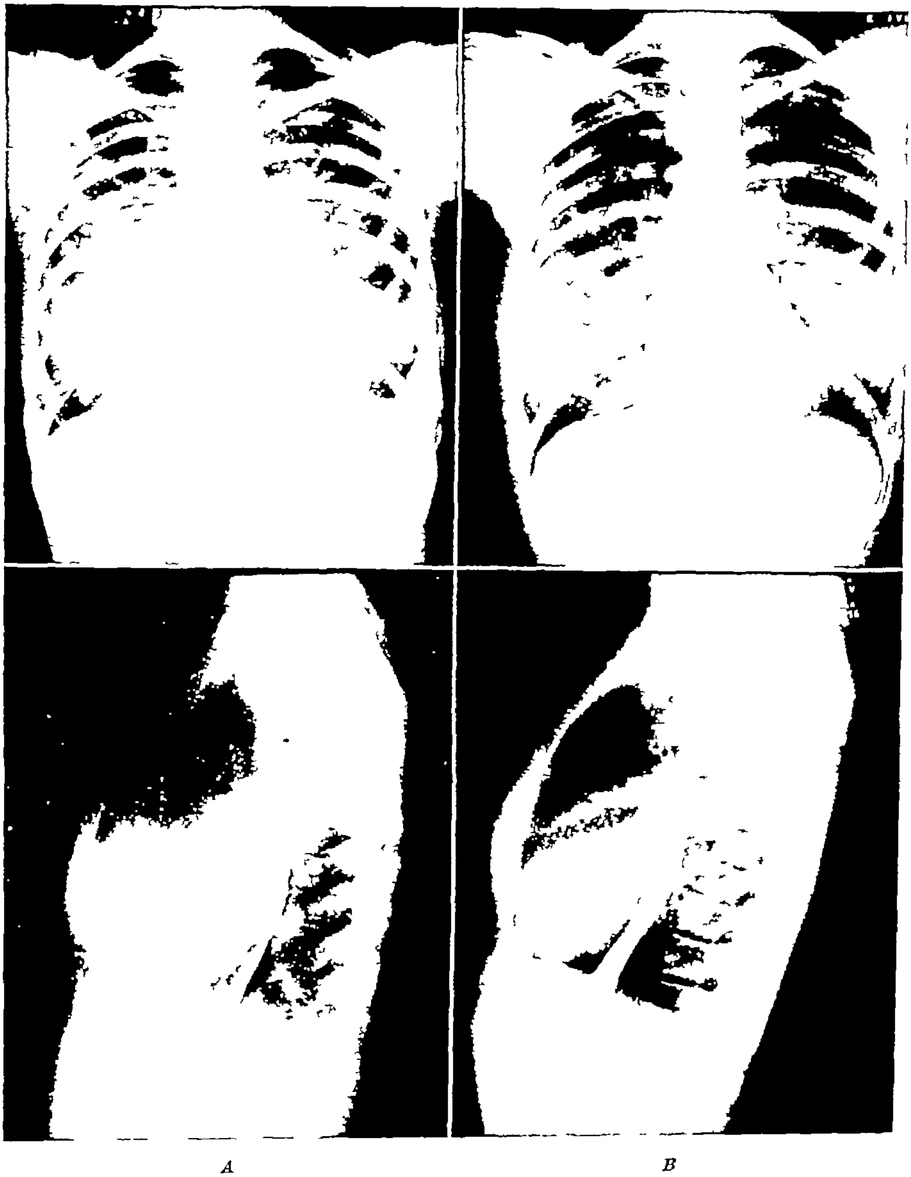

Fig. 1.—E. I. Commissurotomy Nov. 9, 1950. X-ray films taken (*A*) before surgery (Oct. 12, 1950) and (*B*) approximately five years thereafter (Feb. 16, 1955). This is the most dramatic diminution of heart size in this series. Twenty-four per cent of the living patients now have a smaller heart than before surgery.

In ten patients (24 per cent) the over-all heart size was obviously smaller (Fig. 1). This, of course, resulted from the diminution in size of the right ventricle, pulmonary artery, left atrium, and appendage. Nine of these patients, as one would expect, have obtained an excellent result and the tenth is considerably improved (Figs 1 and 2)

In five (13 per cent) the over-all size of the heart was obviously larger This enlargement for the most part was reflected in an increased size of the left

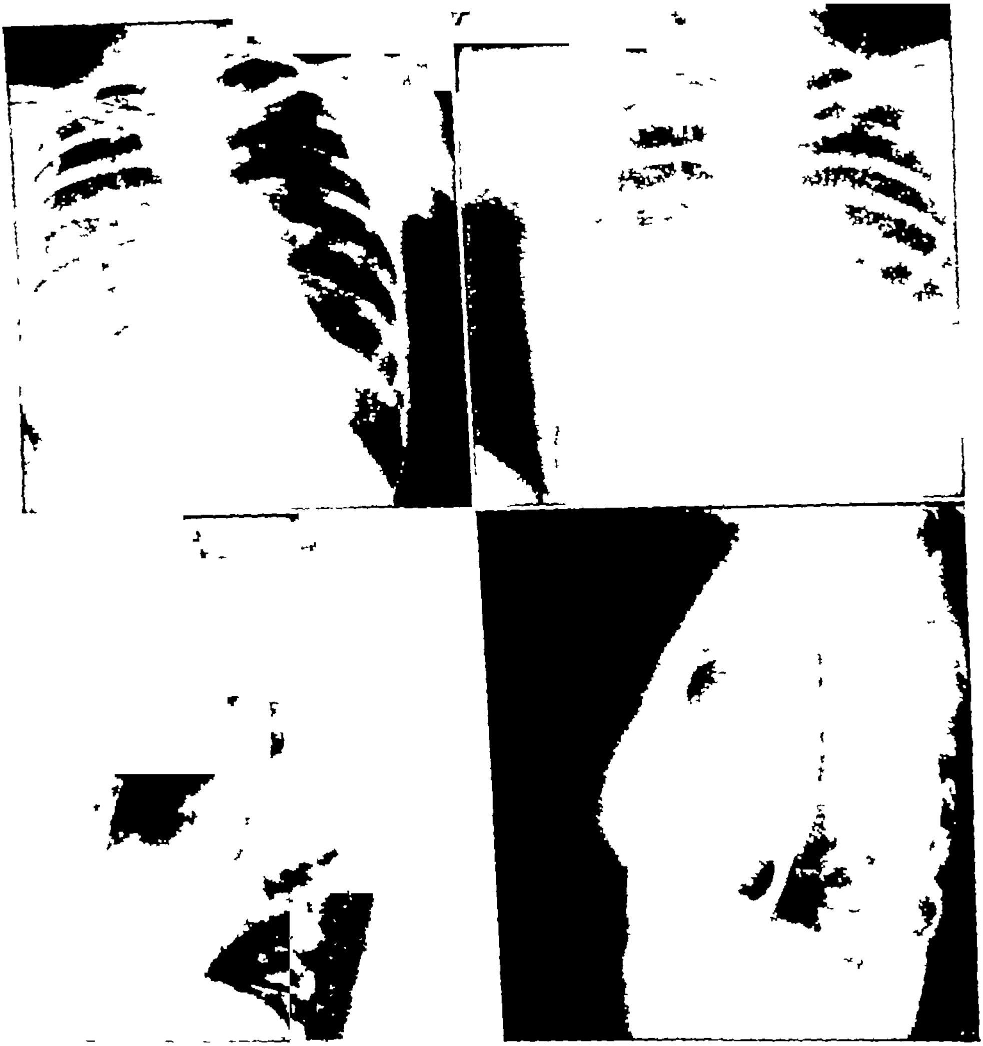

Fig 2 — V S Commissurotomy June 27 1949 The usual degree of diminution in cardiac size noted in ten patients (24 per cent) whose hearts are now smaller than they were before surgery *A* June 21 1949 *B* Feb 15 1954

ventricle and possibly the left atrium Rather paradoxically perhaps four of these patients consider themselves functionally improved and one is unimproved (Fig 3)

In the largest group twenty six patients (63 per cent), there may be room for rather heated discussion In our opinion these hearts, or at least these cardiac roentgenographic silhouettes, remain unchanged There are many who would argue both ways (larger or smaller) in this group, but careful study has indicated that the over-all cardiac mass is essentially unchanged (Fig 4)

The implication of these findings must be very obvious Whereas in the years immediately preceding surgery all these patients were showing progressive enlargement of their cardiac chambers now and very significantly 87 per cent of these hearts are either the same size or smaller This is rather powerful evidence of an objective nature to show that surgery has affected the clinical course of these patients favorably

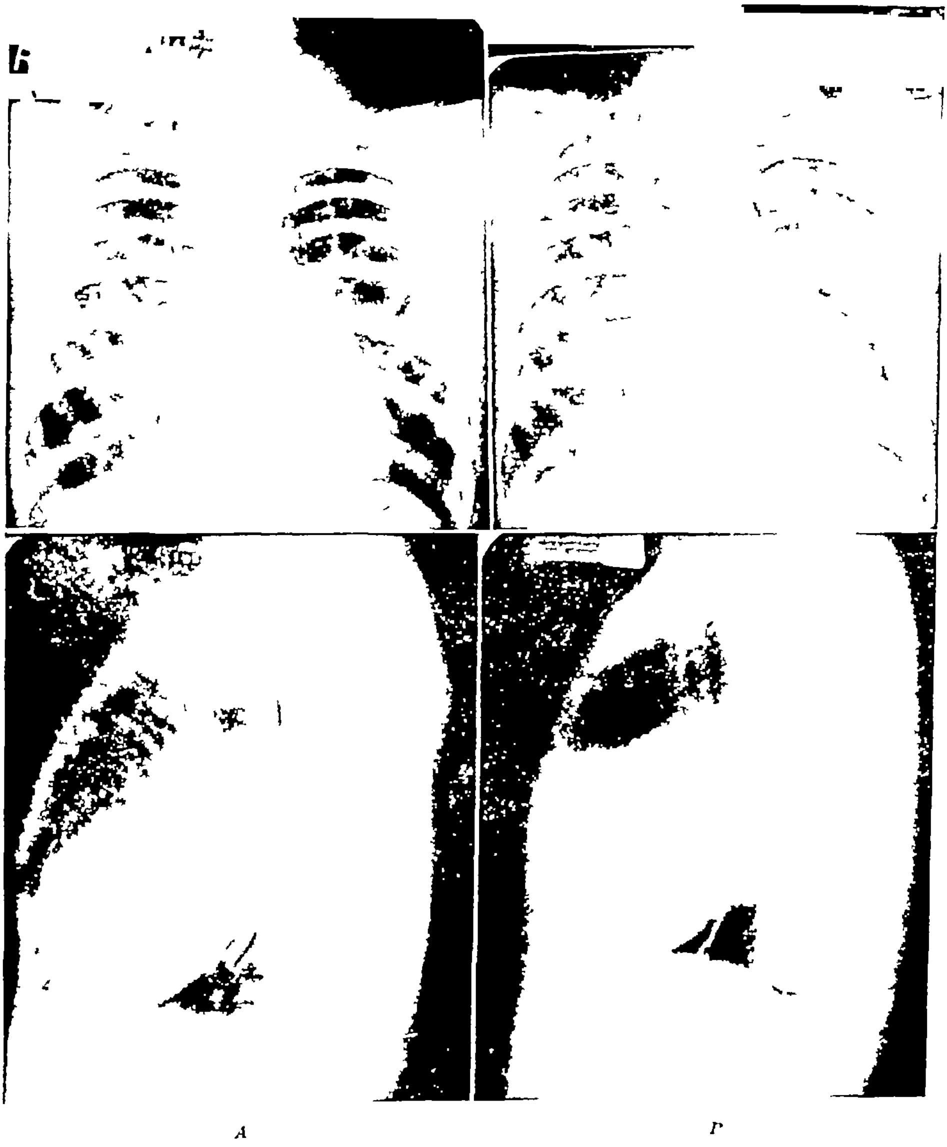

Fig 3—J K. Commissurotomy Nov 23 1949 In five patients (13 per cent) there was some increase in the cardiac silhouette usually to the degree illustrated above *A* Nov 14 1949 *B* March 9 1954

Cardiac Catheterization Data—It is extremely unfortunate that the catheterization studies in this important series of patients could not have been more detailed and complete The preoperative studies were made at a time (five to six and one half years ago) when our facilities for this type of examination were limited and primitive by present-day standards Nevertheless, all data

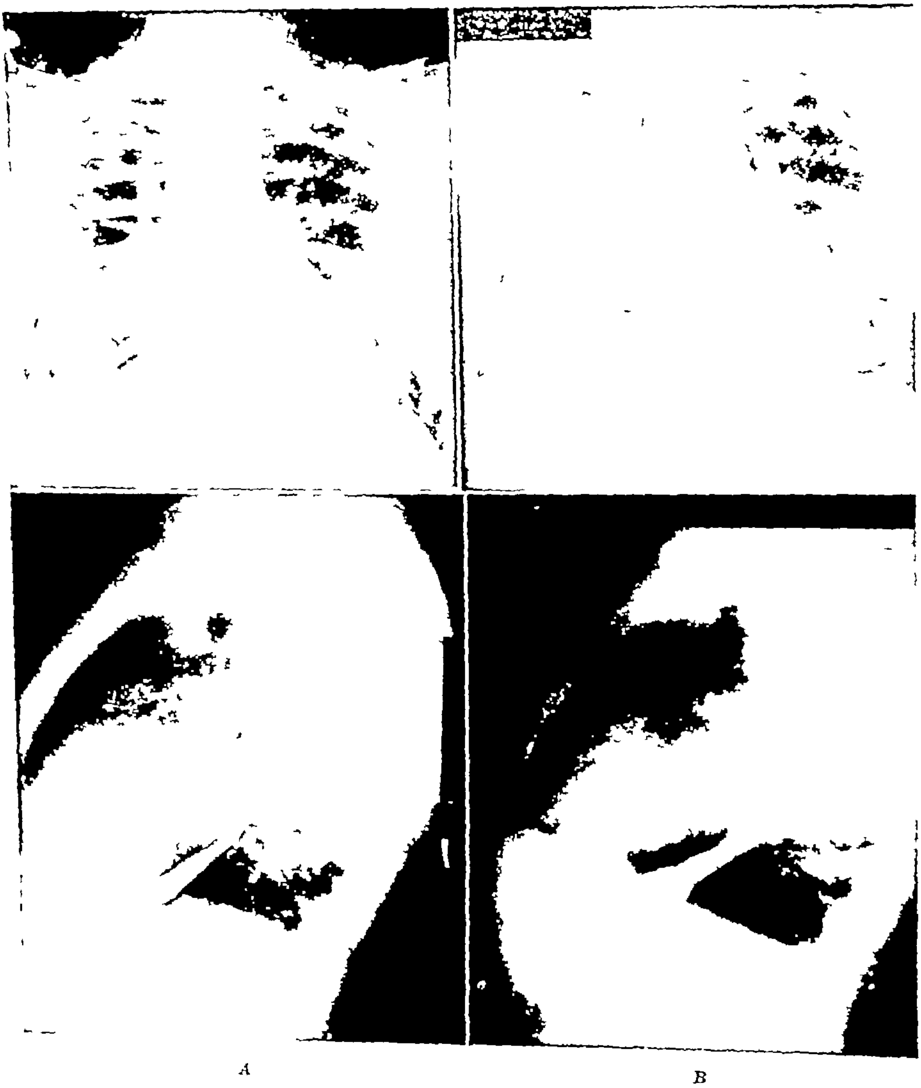

Fig 4 —T S Commissurotomy Nov 7 1949 In twenty six patients (63 per cent) the cardiac roentgenographic silhouette indicative of over all cardiac mass remained essentially unchanged *A* Nov 1 1949 *B* March 3 1954

obtained are presented in Table II Twenty-three of the twenty seven cases in which data are available have obtained functional improvement of significant degree sustained to the present time In all but two of these, the reduced pressure within the pulmonary vascular bed and right ventricle has paralleled and objectively corroborated the clinical improvement In these two (No 11, H E, and No 12, R B), both of whom are in excellent condition today, the pressure drop was slight in one and the pressure was higher in the second As the postoperative catheterization in these was carried out only one month after surgery, it would seem that enough time had not elapsed for the secondary circulation to readjust to its final levels

TABLE II AVAILABLE CATHETERIZATION DATA
(27 of 41 Living Patients)

CASE	PREOPERATIVE		POSTOPERATIVE		CLINICAL	
	RT VENT	PUL ART	RT VENT	PUL ART	MONTHS	RESULTS
1 J B	90/17 (41)	—	48/3 (18)	—	20	Excellent
2 E W	82/2	84/38	56/1	63/19	1	Unimproved
3 V S	141/5 (50)	143/56 (85)	33/14 (20)	36/15 (22)	15	Excellent
4 T S	43/3 (16)	42/12 (22)	27/5 (12)	—	33	Excellent
5 J K	60/4	81/31	23/8	24/6	65	Improved
6 S G	42/?	55/7	7/4	—	1	Improved
7 E M.	55/36 (42)	49/30 (36)	28/0 (9)	35/10 (18)	13	Improved
8 V C	100/9 (39)	130/59 (83)	26/5 (12)	24/8 (13)	21	Excellent
9 G K	50/2 (18)	48/24 (32)	47/4 (18)	52/23 (33)	10	Unimproved
10 W F	25/-1	24/11	—	—	—	Unimproved
11 H E	66/3	54/27	48/8	48/21	1	Excellent
12 R B	36/1	31/15	54/4	—	1	Excellent
13 G D	89/0	87/39	50/-2	50/18	9	Improved
14 F L	68/0 (23)	—	52/2 (21)	—	16	Excellent
15 H D	72/5	78/42	—	—	—	Improved
16 C W	37/4	32/14	—	—	—	Unimproved
17 A N	(37)	(72)	(2)	(14)	61	Improved
18 M S	43/3	48/18	—	—	—	Improved
19 E C	64/-3 (25)	75/27 (43)	30/0 (10)	30/10 (17)	14	Excellent
20 J A	—	57/44	24/30	38/18	12	Excellent
21 E I	93/6 (35)	105/24 (51)	24/-6 (7)	23/4 (14)	61	Excellent
22 A G	59/-7	59/17	—	—	—	Improved
23 M Q	21/7	36/-3	—	—	—	Excellent
24 M. D	32/-2	30/16	20/8	20/6	14	Excellent
25 H O	67/0	68/29	—	—	—	Improved
26 M J	78/5	82/35	—	—	—	Excellent
27 I J	53/0	63/26	48/0	36/15	1	Improved

In the four patients who remained unimproved after surgery, only two were catheterized during the postoperative period but neither of these showed a significant pressure drop, again showing rather close correlation to the observed clinical state

Valvular Findings—It may be stated categorically that in a tight mitral stenosis (an orifice reduced to a size of a cigarette or less), the more pliable the valve the better the result A preoperative demonstration of valvular calcification has often conditioned the surgeon to be cautious in his prognostic statements to the prospective patient Some degree of calcium from a fleck to complete replacement of all valvular tissues was present in twenty (49 per cent) of these patients Although seventeen of these have remained in a definitely improved state to the present time, only six can be considered in excellent functional condition

In those twenty one patients (51 per cent) in whom there was no evidence of valvular calcification, eighteen remain vastly improved to date but, in contrast to the group with calcification, fourteen of the eighteen are considered to be excellent a very decided improvement Even so, there were three with densely fibrotic valves without detectable calcium who are essentially unimproved over their preoperative state

Reactivation of the Rheumatic State—One always hesitates to make emphatic and far-reaching statements concerning the presence or absence of rheumatic activity in a patient who does not show the full-blown syndrome of rheumatic fever in all its aspects This is a condemnation of the medical profession as a whole rather than a reflection on any of its members for such a diagnosis must be made on clinical impression and experience alone, as no definitive or diagnostic tests for specific recognition exist One of us (O H J) was the first to call attention to the possible reactivation of the rheumatic state following surgery and termed it "pleuropericarditis" for this is the common, early presenting symptom-complex of this syndrome[9, 11] Despite an attempt to maintain a conservative attitude toward the existence of this complication, it must be stated that in eight of these forty-one living patients there have been repeated postoperative episodes certainly to be regarded, even without laboratory verification, as rheumatic activation This represents an incidence of 19 5 per cent The clinical manifestations of these rheumatic bouts have included at one time or another all the time-honored stigmata of this disease such as cyclic fevers, painful swollen joints, tachycardia pulmonary and peripheral congestion, and thoracic or precordial pain When one appreciates that this surgery is being carried out in a smoldering bed of rheumatic disease the more significant fact is that all patients do not show evidence of increased rheumatic activity Be that as it may, the fact remains that rheumatic activity does occur after surgery just as it does from time to time throughout the life of any rheumatic patient, whether surgery has been performed or not It is of interest that in only three of the eight patients with postoperative rheumatic activity was there evidence of rheumatic change in the biopsied left auricular appendage Thirteen other appendages of these forty one living patients likewise showed rheumatic stigmata but with no clinical evidence of rheumatic activity

Thromboembolic Data—Despite the fact that the left auricular appendage was traversed in each instance, seven were obliterated by thrombotic material, and that approximately half the valves contained calcium, only one operative embolus was produced This resulted in a complete left hemiplegia from which the patient, by dint of constant perseverance and adherence to a well-managed program of rehabilitation, has obtained complete recovery except for the finer motions of the left hand Clinically this patient has obtained an excellent result and is living a normal and useful life This low incidence is in some contrast to the embolic incidence as found in our first 500 consecutive commissurotomies[12] The over-all embolic incidence in this larger series was 4 4 per cent, of which 2 6 per cent were cerebral and the remainder peripheral There have been no embolic episodes during the postcommissurotomy period to date

Miscellaneous Postcommissurotomy Medical Events—To further attest the improvement obtained and maintained by these patients, it is of interest to note that a considerable number of these patients have undergone unrelated surgery and other medical events, in some instance of a rather serious nature In each instance these have been tolerated without complication or deterioration of their cardiac status Four patients have undergone normal pregnancies and deliveries,[13] in one instance two such episodes, without mishap to either mother or child Two cholecystectomies have been performed, two appendectomies, one of which was for a ruptured appendix, one hysterectomy and one uterine myomectomy, three curettages of the uterus, one hemorrhoidectomy, and one patient survived a rather severe myocardial infarct from which he is now recovering nicely As stated, all these operations and their attendant anesthetics were tolerated without evidence of cardiac disability

SUMMARY AND CONCLUSIONS

1 The first fifty consecutive patients undergoing mitral commissurotomy approximately five to six and one-half years ago have been subjected to a detailed analysis in an attempt to ascertain their present subjective and objective status

2 None of these patients was in Stage I (asymptomatic), five (10 per cent) were in Stage II (statically incapacitating), 36 (72 per cent) were in Stage III (progressively incapacitating), and 9 (18 per cent) were in Stage IV (terminally incapacitating)

3 There was an operative mortality of 6 per cent (3 patients) and subsequent death, 6 weeks to 3 years later, occurred in 12 per cent (6 patients)

4 The remaining 41 patients (82 per cent) are living and these have formed the basis for the following conclusions

5 After a comprehensive study of each living patient, including an appraisal of the patient's subjectively reported clinical state as well as a correlation of the clinical findings, electrocardiographic tracings, teleoroentgenograms, and catheterization data, we conservatively conclude that 30 patients (73 per cent of those living or 60 per cent of the original 50) are in better condition and living a more nearly normal life than they were prior to surgery

6 According to the patients' and their family physician's own appraisal of the present clinical status of these 41 living patients, 36 (88 per cent of those living, or 72 per cent of the original 50) are better after five years than they were prior to surgery (Fig 5)

7 If one were to judge the present clinical status of these patients on the basis of their murmurs alone, it would be impossible to come to any definitive conclusions Only four of these 41 living patients have a heart free of murmurs Eleven have lost all evidence of their original mitral diastolic murmur Fourteen patients now have a mitral systolic murmur of varying degrees which was not present prior to surgery Those patients who have a pure murmur of mitral stenosis indicative of a small mitral orifice (cigarette size or less) routinely obtain the best results from mitral commissurotomy

8 Although the electrocardiographic changes following surgery do not routinely show conclusive evidence of improvement, in a considerable percentage of patients changes are present indicative of a definitive return toward the normal

9 Fluoroscopically and by teleoroentgenographic studies, ten (24 per cent) of the 41 living patients now have a cardiac silhouette which is obviously smaller than it was prior to surgery, 26 (63 per cent) have a cardiac mass which is of the same size as that noted before surgery, and in 5 (13 per cent) the heart size is obviously larger The significant point rests in the fact that now, five or more years after surgery, 87 per cent of the patients have a heart the same size or smaller than it was before surgery, whereas in the years preceding surgery it was progressively becoming larger

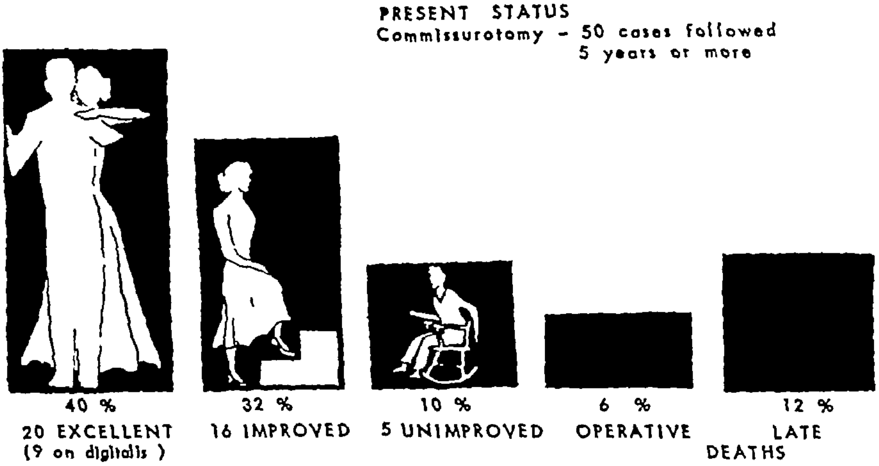

Fig 5—The present status of fifty cases in this series followed five or more years

10 All available cardiac catheterization data parallel and corroborate the observed functional state of the patient whether he be improved or unimproved

11 In 20 (49 per cent) of these patients valvular calcification was present and the degree of improvement in these, although quite satisfactory, was not as great as that seen in the 21 (51 per cent) cases whose valves were free of calcium deposits

12 Definite evidence of rheumatic activity was observed during the postoperative period in eight patients (19 5 per cent)

13 No evidence of valvular restenosis has been observed in the 41 living patients nor in the valves of those who died in the postoperative period

14 Only one operative embolus was produced in these 50 patients and that patient has obtained complete recovery of her left hemiplegia except for the restoration of the finer motions of the left hand There have been no postoperative emboli to date (12 per cent prior to surgery)

15 There is no question in our minds but that commissurotomy has been of untold value to the majority of patients in this series and for the most part

that degree of improvement obtained in the first postoperative year has been maintained over a five-year *period* There is no reason to suppose that it will not continue

16 It is perhaps permissible to postulate that could the technical experience obtained in our over-all series of 740 commissurotomies have been applied to these first fifty consecutive patients the results might well have been considerably better

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DISCUSSION

DR DON L FISHER, Pittsburgh, Pa —Have any valvular lesions occurred postoperatively? Do you now follow the recent recommendation of the American Heart Association, to place all patients with rheumatic heart disease on penicillin permanently?

DR ROBERT P GLOVER (Closing)—To answer the question regarding the advisability of the postoperative prophylactic use of long term antibiotics following mitral commissurotomy, our practice has been as follows All patients have been advised to continue the use of oral penicillin, 200,000 units twice daily, for the first postoperative year Thereafter, it has been suggested that this medication be taken during the winter months and at other times whenever symptoms of upper respiratory infection develop We have had no way of checking the efficacy of this program but have felt that adherence to such a regimen might well check or minimize the recurrences of rheumatic episodes

Quite probably most patients have not accepted this advice or have not carried out such a program over a long period of time In any event, Dr Janton, our cardiologist, has noted on a number of occasions, in our over all series of 800 mitral commissurotomies the appearance of murmurs in the aortic area not present prior to surgery Presumably this may represent additional rheumatic valvular disease but whether this represents a manifestation of new pathology or merely a continued development of old pathology cannot be stated

CONSIDERATIONS IN THE SURGICAL TREATMENT OF VENTRICULAR SEPTAL DEFECTS

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THE impression is gained from the literature, as well as from many of our medical and pediatric confreres, that ventricular septal defects are fairly benign, congenital cardiac malformations. It is not until one critically reviews a large number of his own cases, not only on clinical grounds but also by roentgen, cardiographic, and catheterization studies, that the fallacy of this impression becomes obvious.

Ventricular septal defects were first described by Roger[1] in 1879. He was impressed by what appeared to him to be the lack of objective signs and symptoms other than the finding of a harsh systolic murmur. He felt that it represented a lesion that was fairly well tolerated by the individual, yet, his conclusions were drawn on patients who were followed for relatively short periods of time in which there was no pathologic verification. These views on the benignancy of the condition, based on such incomplete evidence, have prevailed to the present time and are still quoted by leading texts on this subject. Abbott,[2] in 1932, reported 55 isolated ventricular septal defects, stating that symptoms were usually absent and that cardiac function was seldom disturbed. She also has been extensively quoted as to the benignancy of the lesion, yet, in 1936[3] she stated that the average age of death was 14.5 years, which does not bear out this impression. In her excellent text, Taussig[4] differentiates between the small (less than 1 cm.) type of defect described by Roger,[1] which presumably is well tolerated, and the larger, higher-placed type of defect in which the prognosis for the patient is more guarded. The complications of bacterial endocarditis and secondary changes in the pulmonary vasculature are mentioned, but the serious import of the latter complication is not really stressed.

With the more precise diagnostic method afforded by cardiac catheterization, these views are rapidly changing. This change in attitude should be further accelerated by the marked improvement shown in the few patients who have undergone surgery for closure of ventricular septal defects. Evidence demonstrating that ventricular septal defects may be a serious threat to life is now accumulating. All of the 24 patients whom we have studied have shown a considerable shunting of blood through the defect, and an elevated right ventricular and pulmonary artery pressure. In some cases it

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From the medical and surgical services of St. Luke's and St. Vincent Charity Hospitals and also from the surgical laboratory of St. Luke's Hospital.

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has been estimated that as much as 50 per cent of the left ventricular outflow is shunted into the right ventricle and pulmonary circulation. Others have confirmed such findings.[3] Of 34 patients who died with ventricular septal defects studied by Edwards,[6] 25 were infants who died under 1 year of age. Some of them had other causes of death. Lillehei[7] has reported an average pressure of 70 mm Hg in the right ventricle in 29 patients operated upon. As noted in Table I there appears to be a correlation between the percentage and duration of shunt flow and the right ventricular and pulmonary artery pressures, that is the greater the shunt flow the higher the pressure obtained in the right ventricle and pulmonary artery up to a certain point. When the pulmonary hypertension and pressure within the right ventricle begin equalizing the left ventricular pressure shunt flow will diminish and might even reverse indicating the severe changes in the pulmonary vasculature. Generally, there is a significant degree of arterial desaturation associated with the higher pulmonary pressures.

TABLE I. CARDIAC CATHETERIZATION FINDINGS ON TWENTY TWO PATIENTS WITH VENTRICULAR SEPTAL DEFECTS

NAME	AGE	VOL. % O_2		PRESSURE (MM. HG)		O_2 SAT %
		RA	PV	RV	PA	
C. W.	3	13.79	15.50	44/8	40/14	93.4
D. S.	1.5	8.14	10.17	28/2		
J. B.	3.5	9.37	11.36	34/2	28/9	
K. H.	3.5	9.49	10.09	37/3		90.1
J. R.	4	10.52	11.12	34/0	34/7	94.0
L. F.	5	10.40	9.72	100/25	100/66	87.2
G. C.	5	9.90	14.20	80		89.2
J. B.	6	7.17	10.40	98/2	92/52	85.4
D. D.	6.5	9.35	12.82	94/12	94/40	94
G. G.	6.5	14.94	17.9	103/3	100/60	77.7
P. M.	7	12.3	14.23	38/2	38/8	97.5
S. V.	7	10.9	14.9	61/5	52.4/20	87
D. L.	9	8.01	8.87	92/4	66/12	79.1
N. B.	11	11.1	11.24	116/12	116/76	83.1
B. W.	12	10.2	14.12	30/3		93.5
B. F.	15	10.4	13.33	36/2	25/12	94.8
C. D.	15	12.1	13.6	73/12	68/25	90
M. F.	17	12.15	14.03	108/4	104/50	78.1
T. M.	19	17.3	20.3	55.5/17	55/18.7	87
I. M.	20	14.27	15.9	80/3		95.8
V. L.	21	12.53	14.67	52/2	33/5	93.4
P.	52	11.9	13.45	78/0		65

Analysis reveals a correlation between the percentage and duration of shunt flow and the right ventricular and pulmonary artery pressures. Generally there is a significant degree of arterial desaturation associated with the higher pulmonary pressures.

Repeat catheterization studies performed on the same patients over a period of one to two years have demonstrated progressive elevation of the intracardiac and pulmonary artery pressures in most instances. In a few the catheterization studies have not shown a significant increase over this period of time. In some patients with essentially static cardiac catheterization findings a progression of clinical symptoms and general disability was noted. The pulmonary vascular bed is able to accommodate the increased flow through the lungs initially. Later, pulmonary hypertension, right ventricular hypertrophy and mediosclerosis of the pulmonary vessels develop (Fig. 1).

There has been some controversy as to the etiology of the pulmonary vascular changes Edwards,[8, 9] in particular, has postulated that these changes are an additional congenital defect similar to those noted in primary pulmonary hypertension Dammann and associates,[10, 11] on the other hand, feel that these changes are not congenital but are the result of long standing pulmonary hypertension resulting from increased blood flow through the shunt Unfortunately, these vascular changes from pulmonary hypertension may reach a stage where they are no longer reversible and surgery directed toward closure of the defect will either end in failure or do the patient little, if any, good

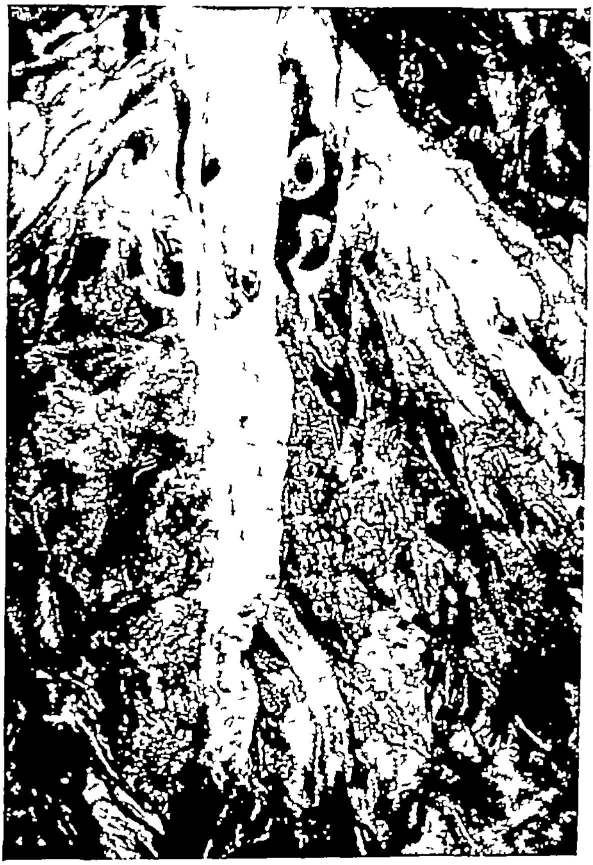


Fig 1 —Gross specimen illustrating the marked degree of pulmonary mediosclerosis associated with pulmonary hypertension secondary to a septal defect and increased pulmonary blood flow

There is no question about the desirability of closure of significant ventricular septal defects The problem should be focused on the perfection of surgical techniques and the crystallization of the indications and contraindications for surgical intervention One must be cognizant of the facts that, if benefit is to be derived by surgical closure, such patients should be operated upon before irreversible damage to the pulmonary circulation develops Furthermore, increasing pulmonary and right ventricular pressures add to the risk of surgical intervention Of the 5 patients with ventricular septal defects operated upon by us the average right ventricular pressure in the three patients who died postoperatively was 98 7 mm Hg and their arterial oxygen saturation was 89 4 per cent, as compared to a pressure of 62 mm Hg and an arterial saturation of 94 6 per cent in the two successfully treated patients In our experience infants and children with ventricular septal defects have shown evidence of elevated pulmonary pressures and failure at a much earlier age than those with atrial septal defects Our studies have shown that when the ventricular pressure is over 90 mm Hg, in the presence of arterial saturation of less than 90 per cent, pulmonary vascular changes that might not be reversible undoubtedly have taken place Other factors however, must be taken into consideration, such as the age of the patient, duration during which elevated pressures have existed the size of the heart, the degree of pulmonary vascularization (by x-ray) and the pulmonary reserve One must weigh the risks of operation against the dangers of waiting

Patent ductus arteriosus, atrial septal defects and ventricular septal defects, from a physiologic standpoint represent essentially the same type of lesion, that is one with left to right shunting of blood with overloading of the pulmonary circulation The indications for surgery, with few exceptions, in patent ductus arteriosus have approached the ideal When the diagnosis is made and the optimum age for surgery is reached, the operation is performed Unless the patient is getting into severe difficulties, we follow essentially the same pattern with atrial septal defects Many of our patients, however, first come to us well beyond this age group Ventricular septal defects are handled somewhat differently If the ventricular septal defect is tolerated fairly well on the basis of such clinical findings as exercise tolerance and accepted weight gain and if the x-ray picture and cardiogram are not significantly abnormal or show no rapid progression, the child may be followed to an optimum time for surgical correction If clinical symptoms and cardiographic and x-ray changes are severe, however, catheterization should be carried out early and if intraventricular and pulmonary pressures are elevated surgical repair of the defect must be given serious consideration

TECHNIQUES

Early attempts at closure of ventricular septal defects utilized so-called "closed techniques" Murray [12] in 1948, attempted to close ventricular septal defects by passing fascia lata strips in an anteroposterior direction through the ventricular septum and defect In 1952 Bailey and his associates[13] employed transventricular pericardial grafts to plug the defect However such grafts tend to become atrophic fibrotic and ineffective In 1953[14] we performed the first closure of a ventricular septal defect by suture technique in a 20 year old white girl employing a "closed technique" Although a murmur is still present this patient has been significantly improved by operation and now leads a normal life. Catheterization studies performed eighteen months postoperatively demonstrated a reduction in the right ventricular pressure from 80/3 mm. Hg preoperatively to 40/4 mm. Hg afterward. The oxygen studies preoperatively were 13 volume per cent in the superior vena cava, 12.5 volume per cent in the inferior vena cava, 14.27 volume per cent in the right atrium, and 15.9 volume per cent in the right ventricle. These changed postoperatively to 11.07 volume per cent oxygen in the superior vena cava, 12.21 volume per cent in the inferior vena cava, and 12.69 volume per cent in the right ventricle. The sample from the right auricle was in the region of the coronary sinus.

Swan[15] and Bailey[16] have attempted closure of ventricular septal defects by direct suture through the open right ventricle, employing hypothermia without success. Gibbon[17] has employed the open technique in a 38 year old man, maintaining the cardiorespiratory functions by an extracorporeal circuit for twenty-six minutes. This patient died five hours postoperatively. The greatest success has been experienced by Lillehei, Varco, and their associates in employing cross circulation while closing ventricular septal defects through the open heart. Their latest report[7] revealed 22 successful closures and 7 postoperative deaths with this technique. During the past two years we have operated upon six patients with ventricular septal defects. One of these patients was an 11-month old baby with tetralogy of Fallot. Four patients have been operated upon through an open cardiotomy. In three, cross circulation was employed and, in one, a pump with a reservoir of arterial blood was used. In only one patient was the operation successful. Two patients have been operated upon by "closed techniques"—one successfully, as reported previously, and the second unsuccessfully. This latter patient was a 5-year-old girl with pulmonary pressures of 100/60 mm. Hg and an arterial saturation of 89 per cent. The catheter apparently had withdrawn at the time of the ventricular sample and she was thought to have an atrial septal defect as well as a ventricular septal defect. The right auricle was explored first. The atrial septum was intact, but a ventricular septal defect could be palpated beneath the septal leaflet of the tricuspid valve. The defect was being closed by means of one of the "closed techniques" developed in the laboratory, which will be described later, when ventricular fibrillation developed. The heart could never be restarted after the ventricular fibrillation was finally stopped.

Regardless of the ultimate technique used, the surgeon must be cognizant of certain facts regarding the anatomy, pathology, and physiology of ventricular septal defects which dictate the precise way in which they must be closed. Ventricular septal defects are most commonly located in or just anterior to the membranous septum, just proximal to the aortic valve on the left ventricular side and adjacent to the septal leaflet of the tricuspid valve on the right ventricular side (Fig. 2). They are found less commonly in the muscular septum. This discussion will be limited to the high membranous defects. Occasionally, small defects may be bounded by a well-defined septal edge

However most of the patients who die from their septal defects or who have defects causing sufficient disability to warrant operation have larger defects and there is little or no septal tissue on the upper border because of the failure

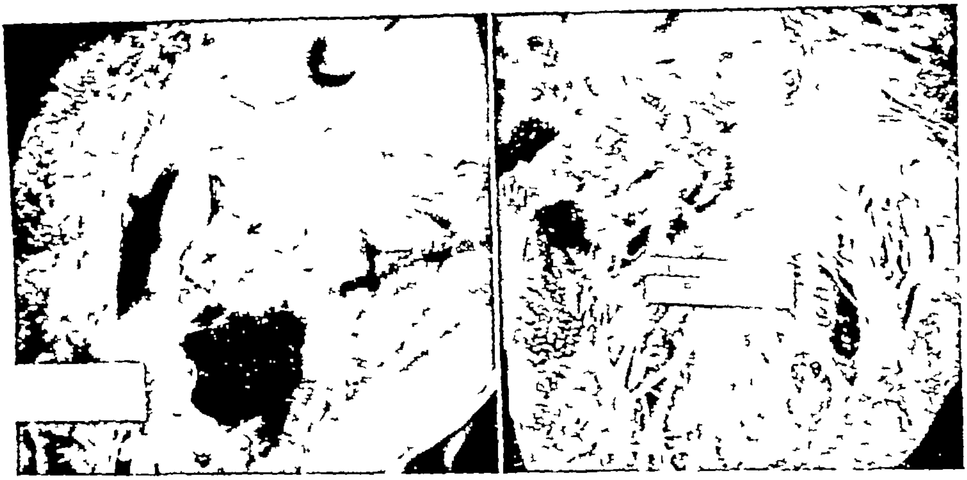


Fig 2.—A Photograph of a large ventricular septal defect in a 5-year-old girl as viewed through the right ventricle The arrow on the left is at the edge of the septal leaflet while the one at the right overlies the anterior leaflet hypertrophied from the abnormal left to right shunt flow

B Defect from the same patient, as viewed through the left ventricle. Arrows demarcate the edges of the defect The opening of the defect is filled with valvular leaflets from the tricuspid valve.

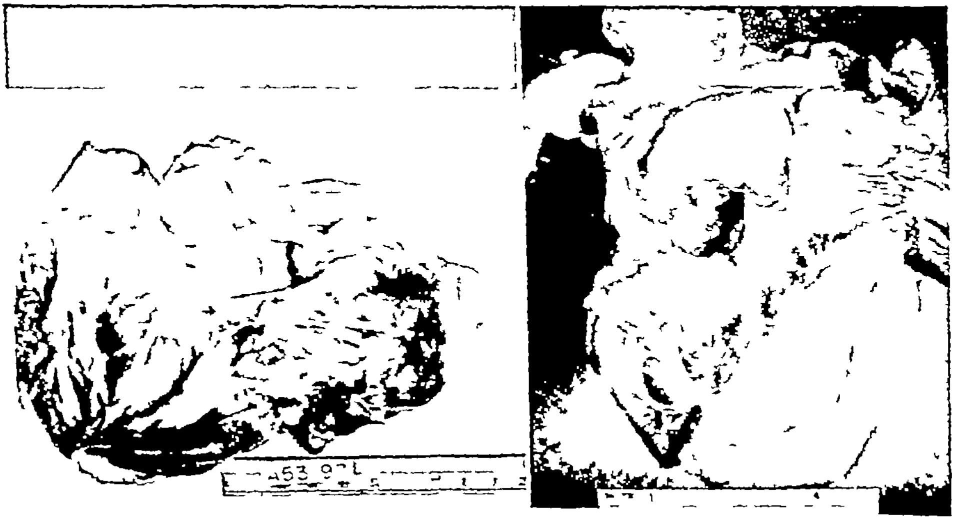
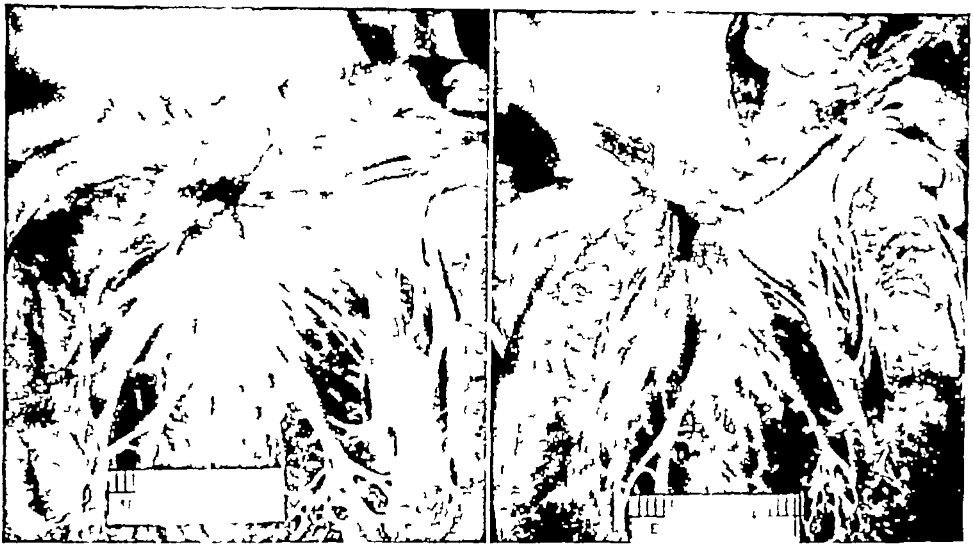


Fig 3.—A Photograph of autopsy specimen from a 16-year-old girl who died of a ventricular septal defect. Defect is located beneath septal leaflet of tricuspid valve Only the lower portion of the defect can be visualized extending beyond the septal leaflet. Arrows demarcate the upper border of the defect beneath the septal leaflet.

B Photograph of autopsy specimen from a 1-year-old infant who died of a ventricular septal defect, which demonstrates the absence of septal tissue above at the aortic valve and the half circle contour of the defect.

of the aortic septum growing down to fuse with the ventricular septum. Instead of being round, such defects are in the shape of a half circle, the upper edge of which may be formed by the annulus of the aortic and tricuspid valves (Fig. 3). In some instances there is slight overriding of the aortic valve so that, in essence, there is little tissue, if any, above to suture to without incorporating either the aortic or tricuspid leaflets. It is mandatory that such defects be closed in a longitudinal manner approximating the apical surface of the defect to the annulus, as demonstrated in Fig. 4. If such defects are closed in a transverse direction, it is impossible to close them completely without embarrassing the aortic outflow tract. It should be stressed that the defect, when viewed through the open right heart, is frequently covered by the crista supraventricularis and that this landmark must not be mistaken for the lower edge of the defect or used in its closure. Lillehei and his associates have accomplished closure by two one-half purse string sutures. When there is some septal tissue above, this appears to be a satisfactory technique. In a number of specimens examined, however, either the septal tissue above is lacking or it is so concealed under the septal leaflet of the tricuspid valve that it is difficult or impossible to see and to close it without incorporating either an aortic cusp or part of the tricuspid leaflet, even though the valve leaflet is retracted and its papillary muscle severed. In many instances it appears that such defects, when lacking in septal tissue above, can be closed better by passing the suture from the lower edge out through the pliable myocardium



A *B*

Fig. 4.—*A*, Gross specimen of a ventricular septal defect viewed through the open left ventricle demonstrating the correct apposition of the lower edges of the defect to the aortic annulus in a longitudinal direction. Defects closed in this manner do not occlude the aortic outflow tract or aortic valve. Edges of opened aortic valve are demarcated by arrows.

B, Same defect as above demonstrating partial occlusion of aortic valve when ventricular septal defect is closed in a transverse direction.

just proximal to the aortic valve at the junction of the aorta and right auricle which can be easily seen by retracting the right auricular appendage (Fig 5) This is in a region free of the coronary vessels This technique is particularly useful in operating upon patients with an overriding aorta, in which case the overriding and septal defect are closed at the same time When such defects are closed in this manner there is no danger of incorporating either the aortic cusps or tricuspid leaflets This technique can be employed in either open or closed myocardiotomies The position of the incision into the right ventricle is also of importance Unless it is necessary, in cases of associated pulmonary or infundibular stenosis, to make the incision along the pulmonary outflow tract it should be placed in the direction of the right ventricular inflow tract so that significant coronary arteries are not severed with resulting myocardial ischemia

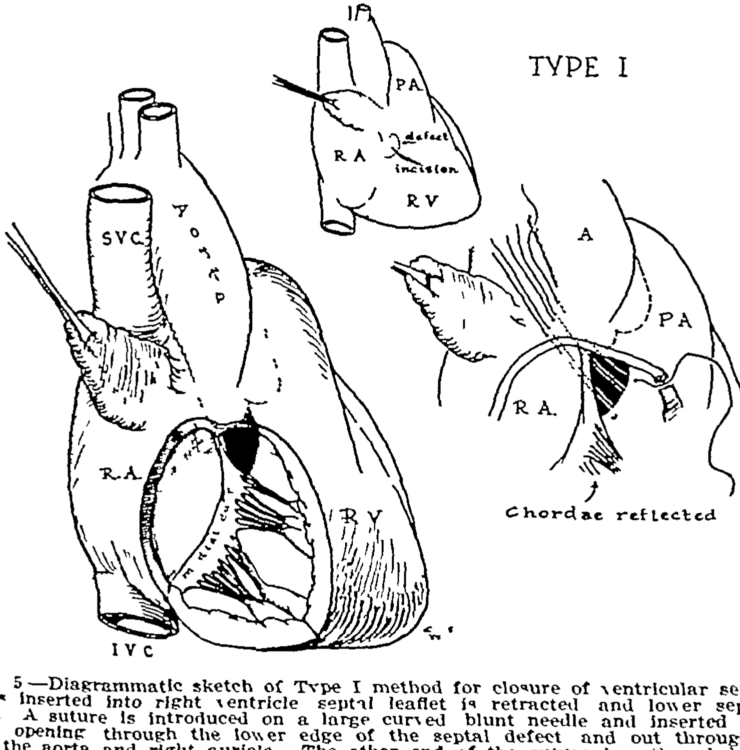


Fig 5—Diagrammatic sketch of Type I method for closure of ventricular septal defects Finger is inserted into right ventricle septal leaflet is retracted and lower septal edge is palpated. A suture is introduced on a large curved blunt needle and inserted through the myotomy opening through the lower edge of the septal defect and out through the angle between the aorta and right auricle The other end of the suture is rethreaded and passed in a similar manner Several sutures are placed and tied by the assistant as directed by the surgeon s intracardiac finger (see text)

In approximately ten months experience with the use of controlled cross circulation both in the laboratory and clinically many problems have arisen of which some are applicable to the cross-circulation technique per se and others are applicable to open cardiotomy using any type of artificial pump oxygenator

Obviously the critical aspect of the cross circulation technique is the proper preoperative balance between the donor and recipient circuits and the